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Elsdon:
Here is some information regarding Irrigation Efficiency and Distribution Uniformity data we have. If you have any questions, please call me.
Thanks,
Baryohay

AN ANALYSIS OF MOBILE LABORATORY IRRIGATION SYSTEM EVALUATION DATA: AGRICULTURAL SYSTEMS

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Introduction

During the past 10 years, mobile laboratories sponsored by state and federal agencies have evaluated irrigation systems for growers. Data collected by these laboratories can help assess the uniformity and efficiency of the applied water and identify problems with system design or management. Recommendations then are made for improving system performance. These evaluations provide site-specific information to aid in making system or management changes.

Thus far, 936 agricultural irrigation systems have been evaluated. These evaluations provide a data base on performance characteristics of various irrigation systems and on problems in both design and management of an irrigation method. Thus, the objectives of this study are: 1) develop a data base of the information contained in the mobile laboratory reports, 2) analyze the data for uniformity and efficiency characteristics of the various irrigation methods, and 3) identify common characteristics and problems related to system performance. The reports of the mobile laboratories were provided by the Office of Water Conservation of the State Department of Water Resources.

Evaluating Irrigation System Performance

Major performance characteristics of irrigation systems are uniformity of applied or infiltrated water and irrigation efficiency. The uniformity is described by the distribution uniformity, which is the minimum depth infiltrated divided by the average depth infiltrated. The minimum depth infiltrated frequently is defined as the average of the lowest one-fourth of the measured or estimated amounts of infiltrated water, called the average of the low quarter. Irrigation efficiency is the amount of water beneficially used divided by the average amount of applied water. If the amount of beneficial use equals the amount infiltrated in the low quarter, then the distribution uniformity is about equal to the irrigation efficiency. Thus, the distribution uniformity is a measure of the maximum potential irrigation efficiency of a properly-managed irrigation system.

The evaluation procedures used by the mobile laboratories were developed by personnel at California Polytechnic State University at San Luis Obispo. A major objective of these procedures is to calculate a field-wide distribution uniformity reflecting all factors affecting the uniformity of water infiltration or application. The product of these individual factors if used as the field-wide distribution uniformity.

The factors contributing to the field-wide distribution uniformity used in these evaluations are:

1. Furrow and border irrigation - nonuniform infiltration due to advance time/irrigation time, variation in irrigation set times, and in soil variability, estimated from soil texture data. It is based more on judgement than on measured data.
2. Undertree sprinklers - variation in application rate due to variable sprinkler spacing, variation in sprinkler discharge due to pressure variation, and sand wear. Catch-can uniformity is not considered. Catch-can uniformity is assumed to be unimportant for tree crops.
3. Hand-move, wheel-line, and solid-set sprinklers - catch-can uniformity, pressure variation, different nozzle sizes, sand wear, lateral drainage, plugged nozzles, and improper rotation.
4. Linear-move/center-pivot sprinkler machines - catch-can uniformity and variation in nozzle flow rates due to pressure variation.
5. Low-volume (drip/trickle, micro-sprinklers) irrigation - variation in emitter flowrates due to pressure variation and variation in flowrates due to plugging, manufacturing variation, variable emitter spacing, and lateral drainage.

Results

The total number of data sets was 936. Low-volume irrigation consist of 458 sites, continuous-move sprinkler machines - 57, hand-move/wheel-line/solid-set sprinklers - 164, undertree sprinklers - 28, furrow irrigation - 157, and border irrigation - 72.

The average distribution uniformity and irrigation efficiency for each irrigation method are shown in Table 1. The distribution uniformity is a one-time measurement, while the irrigation efficiency is based on estimates of seasonal crop water use and applied water.

Furrow and border irrigation had the highest average distribution uniformity, statistically different from those of the other irrigation methods except the undertree sprinklers. Hand-move/solid-set sprinklers had the lowest average distribution uniformity, also statistically different from the other distribution uniformities. The average distribution uniformity of low- volume irrigation systems was statistically similar to that of continuous-move sprinkler machines (linear-move and center-pivot machines) and undertree sprinklers, which ranged from 73 to 79 percent.

Relative variability of the distribution uniformities was the highest for the undertree sprinklers (coefficient of variation = 24 percent). The lowest coefficient of variability was for the continuous-move sprinkler machines.

Furrow and hand-move/solid-set sprinklers had the lowest average irrigation efficiency, while the highest average efficiency occurred for the border, undertree sprinklers, and linear move sprinklers. The average irrigation efficiency for low-volume irrigation was intermediate.

Poor correlation was found between distribution uniformity and irrigation efficiency, as shown in Figure 1 for low-volume irrigation. Coefficients of determination for the various irrigation methods ranged from 0.001 to 0.22 (center pivots). Thus, the variation in irrigation efficiency is poorly explained by the variation in distribution uniformity. One major reason for this poor correlation is the role management plays in the irrigation efficiency. Overirrigation causes low irrigation efficiencies even if distribution uniformities are high.

A second reason for the poor correlations is the quality of the data used to calculate the irrigation efficiency. Data used to calculate the irrigation efficiency include an estimate of the seasonal applied water. Information on seasonal amounts of applied water is obtained from flow meters, pumping plant evaluations and power-use records, and irrigation district records. However, many systems evaluated did lacked flow meters. Pumping plants provide information on the flowrate at the time of the test, but different flowrates can occur due to varying groundwater or irrigation conditions. Thus, uncertainty exists in the quality of the applied water data, and in the quality of the estimates of irrigation efficiency. Because of quality considerations, comparisons of irrigation efficiencies among the irrigation methods may not be very meaningful. Thus, only the behavior of the distribution uniformity will be emphasized herein.

It should be noted that the original intent of these evaluation procedures was to make growers more aware of irrigation water management. Thus, applied water data were to encourage growers to consider their water management practices.

Frequency distributions of the distribution uniformities are shown in the histograms in Figures 2 thru 4. The histogram for low-volume irrigation, in Figure 2, shows most of the distribution uniformities to be between 70 and 90 percent, with a maximum frequency of occurrence between 75 and 80 percent, skewed toward the lower values. However, 38 percent of the systems had distribution uniformities exceeding 80 percent. The histograms for sprinkler irrigation shows several different distributions (Figure 3). The distribution frequency for hand-moves etc. shows a peak frequency of occurrence of distribution uniformities between 65 and 70 percent. However, many systems (29 percent) had distribution uniformities below 55 percent. Few systems (15 percent) had distribution uniformities exceeding 80 percent. A uniform distribution occurred for the undertree sprinklers, however, catch-can uniformity was not considered for these systems. The distribution for the continuous-move sprinklers shows a maximum frequency of occurrence between 75 and 80 percent, with most of the distribution uniformities (62 percent) exceeding 75 percent. Distribution frequencies of the furrow and border irrigation systems show 64 percent of the furrow systems and 73 percent of the border systems had distribution uniformities exceeding 80 percent.

Low-volume Irrigation Systems

The average distribution uniformity for each area is in Table 2. Areas with the highest average distribution uniformity are Coachella, Riverside, and Pond/Shafter/Wasco (called the Shafter district), with distribution uniformities ranging from 76 and 80 percent, statistically similar at a level of confidence of 95 percent. The Los Banos district was excluded because of the very small sample size. Lower distribution uniformities were found for the Ventura, Mission, and Cuyama areas, ranging from 63 and 69 percent, also statistically similar to each other. The higher distribution uniformities are statistically different from the lower values at a level of confidence of 95 percent.

Histograms of the districts with high and with low distribution uniformities (not shown) showed a maximum frequency of occurrence of distribution uniformities for the Ventura, Mission, and Cuyama districts to be between about 75 and 80 percent. Maximum frequencies occurred between 80 and 95 percent of the high distribution uniformity districts.

Pressure variation contributions to the distribution uniformity was examined for each area. The topography of the Ventura, Riverside, and Mission districts consisted of undulating terrain compared to the other areas. For the other districts, the terrain was more uniform. Little difference occurred in the average contribution of pressure variation to distribution uniformity between areas with undulating terrain and areas with more uniform terrain (Table 3). Thus, contributions of pressure variation to distribution uniformity in the Coachella and Shafter areas may be mainly from excessive lateral lengths. Undulating terrain is the contributor in the other areas.

Little correlation was found between distribution uniformity and the percent contribution by pressure variation or by clogging, manufacturer variability, etc. This is because similar percent contributions could be found for both high and low distribution uniformities. Thus, systems with distribution uniformities less than 70 percent were examined for the major causes of nonuniformity. Clogging, etc. contributed at least 60 percent of the nonuniformity for 18 percent of these systems, while pressure variation contribution at least 60 percent to the distribution uniformity for 28 percent of the systems. For the remainder of the systems, both contributors to the distribution uniformity were within 40 to 60 percent. These results suggest that clogging probably is not a major problem with many low-volume irrigation systems in California.

Actual distribution uniformities due to pressure variation and due to clogging, CV, etc. also were calculated. Little difference occurred in the average respective distribution uniformities. Values were 85.5% and 85.6% for the respective distribution uniformities of pressure variation and clogging. Histograms of frequency distributions (not shown) revealed similar distributions of occurrence.

Table 4 describes the frequency distributions for acres irrigated, emitter flowrate, and system age for each district. About 50 percent of the low volume systems irrigated less than 20 acres in the Cuyama, Mission, Riverside, and Ventura districts. Few fields exceeded 100 acres. However, the percent of systems irrigating more than 100 acres was 25 and 34 percent, respectively, in the Coachella and Shafter districts. The differences in the acreage distribution reflect the cropping patterns of the various areas. Avocados and citrus are major crops for the areas with the smaller acreages, whereas, grapes and deciduous fruits are grown in the areas with the larger acres.

The frequency distributions of emitter flowrates show many flowrates to be less than two gallons per hour for the Shafter and Coachella areas, suggesting drip/trickle irrigation is a major irrigation method in those areas. However, 86 percent of the systems had flowrates exceeding 10 gallons per hour in the Mission district, suggesting that microsprinklers are the primary irrigation method. Microsprinklers also is the primary method in the Ventura district.

Most low-volume systems were less than 10 years old. However, about 57 percent of the systems exceeded 10 years of age in the Mission district, and 59 percent in the Cuyama district.

System characteristics such as age of irrigation system, acres irrigated, and average emitter flowrate were correlated with distribution uniformity. For acreage more than about 200 acres, distribution uniformities generally exceeded about 70 percent. Below 200 acres, considerable scatter occurred in the distribution uniformity. Little correlation was found between distribution uniformity and acreage. The coefficient of determination was 0.0036.

No correlation was found between distribution uniformity and age of the irrigation system. The coefficient of determination was 0.082.

Distribution uniformity versus average emitter flowrate is shown in Figure 5. A cluster occurs of systems with emitter flowrates less than 2 to 3 gph, reflecting drip/trickle irrigation. A second cluster occurs for flow rates of 5 to 10 gph. No correlation was found between distribution uniformity and average emitter flowrate. The coefficient of determination was 0.0002.

Most of the low-volume systems had flow meters. The percent of systems with flow meters in the Shafter, Riverside, and Ventura districts were 85, 80, and 77 percent, respectively. Sixty-seven percent of the systems in the Mission district and 57 percent in the Coachella district had flow meters. Only 30 percent of the systems in the Cuyama district had flow meters.

Sprinkler Irrigation

The distribution uniformities of hand-move/wheel-line/solid-set sprinklers ranged from 50 percent to 67 percent (Table 5). The districts with the highest distribution uniformities were Monterey and Shafter. The lowest distribution uniformities occurred for the Riverside district. Coefficients of variation ranged from 18 percent (Shafter) to 32 percent (Riverside). The lower coefficients of variation occurred for the districts with the higher distribution uniformities (Monterey and Shafter). The distribution uniformity of the Riverside districts probably reflects very small-scale and possibly part-time farming since most systems irrigated less than three acres.

The Shafter data were used to compare hand-move and solid-set sprinklers. The average distribution uniformities were 64 percent and 65 percent, respectively, for hand-move and solid-set sprinklers, not statistically significant. The standard deviations were 10 percent (solid-set) and 15 percent (hand-move).

Center-pivot machines are mostly in the Cuyama district while linear-move machines are primarily in the Monterey and Shafter districts. Table 6 shows the average distribution uniformities of continuous-move sprinkler machines for each area. Distribution uniformities ranged from 73 to 78 percent. all statistically similar. The small sample sizes were excluded from the statistical analysis.

Statistics for undertree sprinklers are in Table 7. However, data sets of individual areas were too small for any meaningful statistical analysis. The distribution uniformity of the Riverside districts probably reflects very small-scale and possibly part-time farming since most systems irrigated less than three acres.

Little correlation occurred between distribution uniformity and irrigation efficiency, as for low-volume irrigation. Little correlation also occurred with the acres irrigated, which would be expected since designs are similar whatever the field size.

A detailed analysis of the hand-move and solid-set sprinklers was conducted because of the large number of samples. The frequency distributions (not shown) showed maximum frequency of occurrence of distribution uniformity to be between about 60 and 70 percent for both types of sprinkler systems.

Major factors affecting the distribution uniformity of hand-move/solid-set sprinklers are catch can patterns and pressure variation. The correlation between distribution uniformity and the percent contribution of catch-can uniformity to the distribution uniformity was poor, with a coefficient of determination of 0.14. Little correlation also occurred between the percent contribution of pressure variability and the distribution uniformity. Contributions were generally less than 30 percent.

Other factors are mixed nozzle sizes, leaks, plugging, and nozzle wear. The contributions of these factors were small for the most part.

Because of the poor correlation between percent contribution of catch-can uniformity and field-wide uniformity, the catch-can distribution uniformity and the pressure- variability distribution uniformity were calculated for these data sets. The histograms of both sources of nonuniformity, in Figure 6, show a fairly uniform distribution of the catch-can distribution uniformities. However, pressure-variability distribution uniformities were concentrated at distribution uniformities greater than 90 percent. Average catch-can distribution uniformity was 69 percent (standard deviation equaled 12 percent; coefficient of variation was 17 percent). Average distribution uniformity due to pressure variability was 91 percent. The average catch-can distribution uniformity was higher than the average field-wide distribution uniformity (62 percent). This suggests that the catch-can distribution uniformity controlled the field-wide distribution uniformity, which would be expected.

The percent of sprinkler systems reported to have flow meters was 29 percent for the Shafter area, 23 percent for the Los Banos area, and 12 percent for the Cuyama area. No data on flow meters or offset-moves were reported for the Monterey area.

In the Shafter area, ninety percent of the sprinkler systems had 30 X 40 foot spacings. About 41 percent of the systems in the Los Banos area had 30 X 40 foot spacings, while 23 percent had 30 X 45 foot spacings. The majority of systems in the Cuyama area had spacings ranging from 40 X 45 to 40 X 50 to 30 X 60 feet. About 14 percent of the systems offset lateral moves in the Shafter areas, 53 percent in the Los Banos area, and 43 percent in the Cuyama area.

Maximum frequency of occurrence of application rates was between 0.15 and 0.2 inches per hour in the Shafter and Los Banos areas.

Surface Irrigation

Most of the furrow and border irrigation evaluations were conducted in the Shafter and Los Banos areas. The number of evaluations in other areas (Riverside, Coachella, and Monterey), which totaled 15 out of 157 for furrow irrigation and 6 out of 72 for border irrigation, were too few for any meaningful

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analysis.

The frequency distributions of the distribution uniformities for furrow irrigation were similar for the Shafter and Los Banos areas, with the highest frequencies of occurrence between 85 and 100 percent. Nearly 50 percent of the systems had distribution uniformities exceeding 85 percent in the Shafter area, while 65 percent exceeded a distribution uniformity of 85 percent in the Los Banos area. The average distribution uniformities were 79 and 84 percent for the Shafter and Los Banos areas, respectively. Sightly less variability occurred in the Los Banos area (CV = 14 percent) compared to the Shafter area (CV = 19 percent). Little correlation was found between distribution uniformity and irrigation efficiency.

Variables to be used to calculate the field-wide distribution uniformity were advance time, differences in set times, and soil variability. Our analysis showed, however, that very few evaluations attempted to assess the effect of soil variability on the distribution uniformity. At best, the procedure used to assess this factor is highly qualitative, based primarily on judgement. The analysis also showed that either the set time variability is not a problem or the evaluator did not collect any information on set times. Less than 10 percent of the reports showed any distribution uniformity contribution from set time variability. Thus, the advance time contribution of one irrigation set was the primary component used to calculate the field-wide distribution uniformity.

The distribution uniformity of surface irrigation is affected by both the advance time and the set time and by the infiltration rate. The lower the advance time, the higher the potential distribution uniformity while the larger the set time, the higher the potential distribution uniformity. Fields with low infiltration rates will have higher distribution uniformities compared with fields with high infiltration rates for given advance and set times.

An analysis of advance and irrigation set times showed in the Shafter area showed a uniform distribution of advance times between 2 and 12 hours. Few times exceeded about 14 hours. For the Los Banos area, about 30 percent of the systems had advance times between 2 and 6 hours. However, most of systems had advance times exceeding 14 hours compared to the Shafter area. The frequency distributions of set times show about 40 percent of the systems in the Shafter area had set times between 24 and 26 hours (suggesting actual set times of about 24 hours). About 40 percent in the Los Banos area exceeded 24 hours. In the Los Banos area, about 20 percent had set times between 12 and 14 hours, suggesting actual set times of about 12 hours. No particular pattern of occurrence was found for other set times.

In the Shafter area, runoff occurred for 70 percent of the systems, and 70 percent reused the runoff. About 92 percent had runoff in the Los Banos area, with 59 percent reusing the runoff.

No information was reported for furrow irrigation on the use of flow meters. The data suggest that most of these furrow systems received district water.

An analysis of the border irrigation systems, most in the Shafter and Los Banos areas, showed that most systems (67 percent) had distribution uniformities greater than 85 percent in the Shafter area and greater than 80 percent in the Los Banos area (82 percent of sites). The average distribution uniformity was 85 percent for both areas.

These distribution uniformities reflect the distribution uniformity due to advance time. Most evaluators did not provide any information on the distribution uniformity contributions due to variable set times and soil variability.

Nearly 80 percent of the border systems had reported having surface runoff in the Los Banos area; about 48 percent reused the runoff. In the Shafter area, 88 percent had surface runoff, and 84 percent reused the runoff.

No data were reported on the existence of flow meters at any of the areas. The data suggest that most of the systems evaluated received district water.

<u>Crop Type</u>

Table 8 shows the percent of sites versus crop type and the average distribution uniformity. For low-volume irrigation, major crop types were avocado and citrus, with average distribution uniformities of 68 and 80 percent, respectively. The low distribution uniformity for avocado reflects the low distribution uniformities found in the Mission district for low-volume irrigation. The major crop type for continuous-move sprinkler systems was alfalfa, with a distribution uniformity of 76 percent. Crop type for undertree sprinklers was nut crops with a distribution uniformity of 86 percent. Hand-move sprinklers were used mainly on alfalfa, cotton, lettuce/cole crops, and root crops such as sugar beets and carrots. Distribution uniformities were similar for all types. Cotton was the primary crop type for furrow irrigation, while alfalfa was the primary crop type for border irrigation.

Conclusions

This analysis shows no clear trend in distribution uniformity versus irrigation method. This is contrary to the assumption that low-volume irrigation generally will have higher uniformity compared to other irrigation methods. These results showed furrow and border irrigation to have the highest distribution uniformities, and hand-move sprinklers to have the lowest uniformities. Low-volume irrigation was intermediate.

These estimates of distribution uniformity are based on a single measurement in time. For low-volume irrigation, a single measurement probably reflects the seasonal uniformity since these distribution uniformities mainly depend on system hydraulics and clogging, for which little change may occur during an irrigation season. For sprinkler systems such as hand-moves, wheel-lines, and solid-set systems, however, wind greatly affects the distribution uniformity. Thus, the seasonal uniformity may be quite different from a one-time measurement, depending on the wind characteristics at the time of the measurement. However, for continuous-move sprinkler systems and undertree sprinklers, the one-time meausurement is a reasonable estimate of the seasonal distribution uniformity since catch-can uniformity is not a factor.

A different situation exists for surface irrigation because the distribution uniformity can change with time due to changing soil characteristics. Distribution uniformities of early irrigations may tend to be relatively low because of high soil infiltration rates. Uniformities may be higher for later irrigations, when lower infiltration rates may exist. However, no trend of distribution uniformity with time during the year could be found. For example, the average distribution uniformity from January to March was the same as the average from June to August for the Los Banos district.

The mobile laboratory procedures are designed to calculate the field-wide distribution uniformity reflecting the many factors contributing to the uniformity of applied water. The estimates of the distribution uniformity of pressurized irrigation systems probably reflect the field-wide uniformity. However, the distribution uniformities of the surface irrigation methods do not reflect the field-wide uniformity, but instead are based only on variability in infiltration opportunity times along the field length of one irrigation set. Factors such as varying soil texture, varying inflow rates, and varying irrigation set times generally were not considered by those evaluating the surface systems although the evaluation procedure provides a method for considering these factors.

Soil variability throughout a field, generally not considered in the mobile laboratory evaluations, can greatly affect the uniformity of infiltrated water for surface irrigation methods. One research project found that most of the infiltration variability was due to soil variability in a field with soil textures ranging from clay loam to sand. In a field with a more uniform soil texture, research found that soil variability and infiltration opportunity time variability contributed equally to nonuniform infiltration. Thus, when soil variability is considered, field-wide distribution uniformities of surface irrigation methods may be similar or less than those of pressurized irrigation systems, depending on the amount of variability.

The data in Figures 2 and 3 provide an indicator of the potential for improvements of the pressurized irrigation methods. In Figure 2, 38 percent of the low-volume irrigation systems had distribution uniformities exceeding 80 percent. This suggests that with proper design and proper maintenance, distribution uniformities higher than 80 percent are possible for low-volume systems. Similar opportunities exist for continuous-move sprinkler systems (Figure 3). However, in Figure 3, less than 10 percent of the hand-move/wheel-line/solid-set sprinkler systems had distribution uniformities greater than 80 percent, suggesting little potential for higher distribution uniformities, mainly because of wind effects on these systems.

Nevertheless, these results show that one cannot generalize that one irrigation method will always be superior to others. Low-volume irrigation can have very high distribution uniformities, however, in reality, design and management may result in distribution uniformities of low-volume irrigation systems similar to those of other irrigation systems.

Since practical distribution uniformities may be similar for each irrigation system, the selection of an appropriate irrigation system may be based more on its suitability for the particular conditions instead of its distribution uniformity. Low-volume irrigation probably is the best irrigation method for the Ventura, Mission, and Riverside areas, where the topography is undulating. Surface irrigation would be inappropriate for that type of terrain, and sprinkler irrigation may be less manageable compared to low-volume irrigation. On the other hand, surface irrigation may be very appropriate in the Central Valley where uniform slopes exist. Where severe soil variability exists within a field, pressurized irrigation methods probably will be better than surface irrigation.

Table 1. Mean, standard deviation, and coefficient of variation of distribution uniformity and irrigation efficiency. Values with the same letter are statistically similar at a confidence level of 95%.

IRRIGATION METHOD	MEAN (%)	SD (%)	CV (%)
	Distribution Uniformity		
Continuous-Move Sprinklers	75 a	10	13
Hand-Move Sprinklers	62 c	15	24
Undertree Sprinklers	79 ab	16	20
Furrow	81 b	15	19
Border	84 b	14	17
Low-volume	73 a	15	21
	Irrigation Efficiency		
Center Pivot Sprinklers	76 ab	9	12
Linear Move Sprinklers	83 b	12	14
Hand-Move Sprinklers	69 ac	13	19
Undertree sprinklers	81 ab	18	22
Furrow	66 c	14	21
Border	80 ab	14	18
Low-volume	76 a	18	24

Table 2. Mean, standard deviation, and coefficient of variation of distribution uniformities of low-volume systems. Values with the same letter are statistically similar at a confidence level of 95%.

AREA	NUMBER	MEAN (%)	SD (%)	CV (%)
Coachella	58	77a	16	21
Cuyama	20	63b	20	32
Los Banos	9	81	12	15
Mission	89	69b	13	19
Shafter	113	76a	14	18
Riverside	45	80a	12	15
Ventura	124	68b	15	22

Table 3. Mean, standard deviation, and coefficient of variation of the percent contribution of the pressure variation to the distribution uniformity for low-volume systems.

AREA	NUMBER	MEAN (%)	SD (%)	CV (%)
Coachella	49	57	17	30
Cuyama	19	57	17	34
Los Banos	9	59	18	31
Mission	84	49	16	33
Shafter	97	51	24	47
Riverside	45	42	22	52
Ventura	123	59	19	32

Table 4. Frequencies distributions of acres irrigated, emitter flowrate, and system age for each area.

PERCENT OF SITES

AREA (acres)

	0-20	20-40	40-60	60-80	80-100	≥100
Cuyama	55	30	5	0	5	5
Mission	72	10	4	1	1	10
Shafter	5	18	19	12	12	34
Riverside	51	24	9	7	2	7
Coachella	12	14	28	5	17	25
Ventura	51	23	11	10	2	4

EMITTER FLOWRATE (gph)

	0-2	2-4	4-6	6-8	8-10	≥10
Cuyama	25	25	10	20	5	15
Mission	7	0	0	3	3	86
Shafter	56	9	5	7	1	22
Riverside	27	14	5	14	9	32
Coachella	41	25	4	10	12	8
Ventura	20	6	4	12	15	43

SYSTEM AGE (years)

	0-5	5-10	10-15	≥15
Cuyama	29	12	59	0
Mission	15	27	28	29
Shafter	41	36	13	9
Riverside	9	53	31	6
Coachella	50	26	24	0
Ventura	39	19	20	23

Table 5. Mean, standard deviation, and coefficient of variation of distribution uniformities for hand-move/solid-set sprinklers for each area. Values followed by the same letter are statistically similar at a level of confidence of 95%.

AREA	NUMBER	MEAN (%)	SD (%)	CV (%)
Coachella	2	51	16	31
Cuyama	24	58 ac	15	26
Los Banos	14	60 abc	18	30
Mission	3	74	12	16
Monterey	36	67 b	13	19
Shafter	65	65 ab	12	18
Riverside	11	50 c	16	32
Ventura	3	56	17	30

Table 6. Mean, standard deviation, and coefficient of variation of distribution uniformities for continuous-move sprinkler machines.

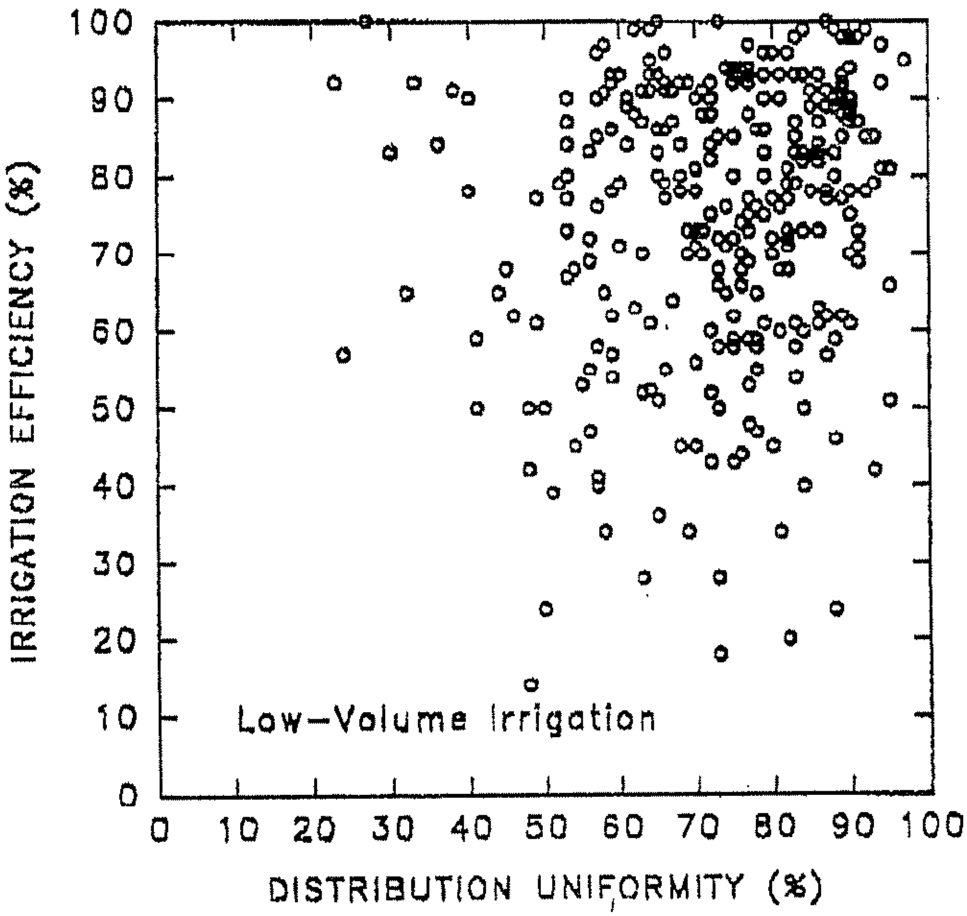
AREA	NUMBER	MEAN (%)	SD (%)	CV (%)
Coachella	1	78	--	--
Cuyama	14	73	6	8
Los Banos	1	77	--	--
Mission	--	--	--	--
Monterey	9	74	9	12
Shafter	32	78	10	13
Riverside	--	--	--	--
Ventura	--	--	--	--

Table 7. Mean, standard deviation, and coefficient of variation of distribution uniformities for undertree sprinklers.

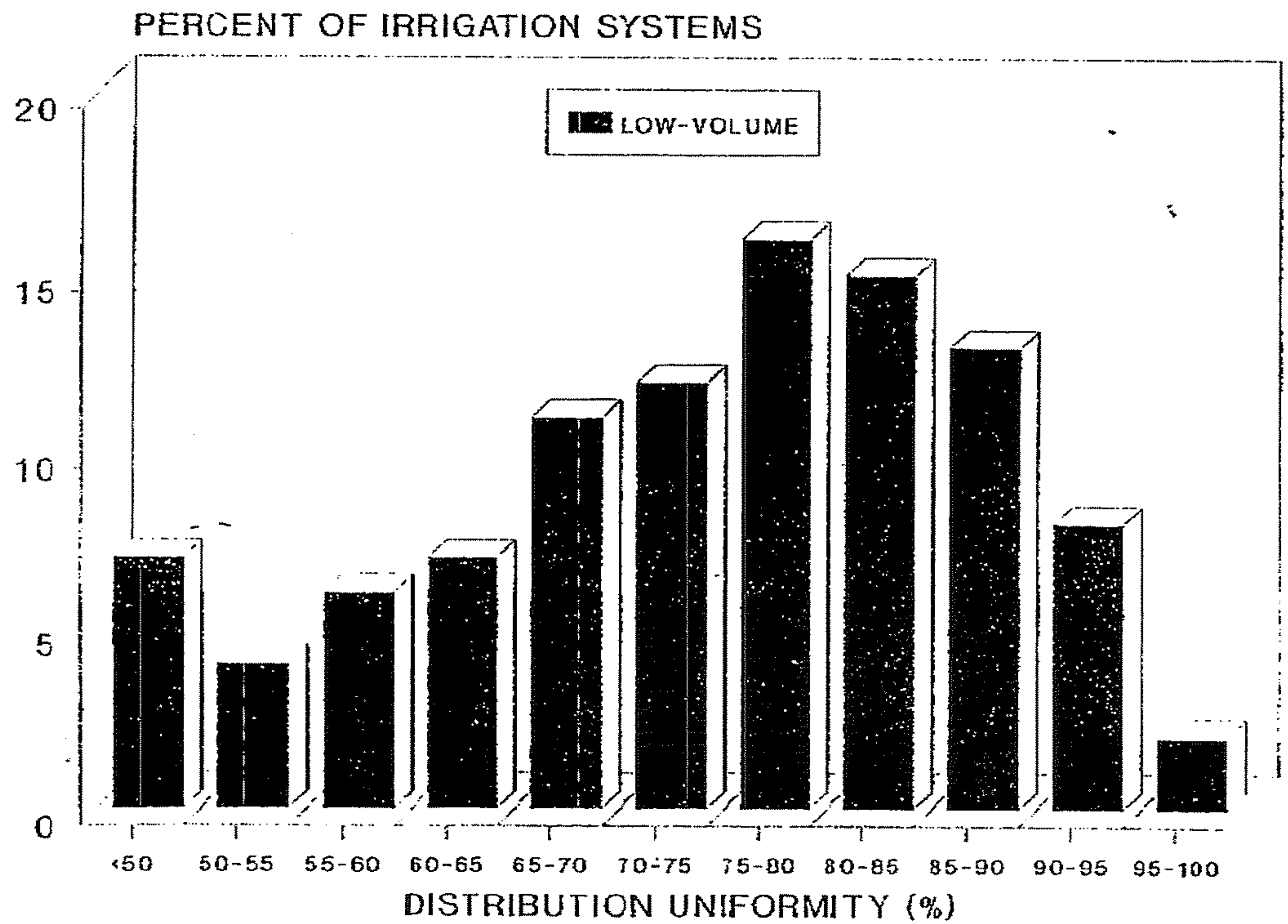
AREA	NUMBER	MEAN (%)	SD (%)	CV (%)
Coachella	--	--	--	--
Cuyama	2	86	4	5
Los Banos	8	83	8	10
Mission	--	--	--	--
Shafter	7	90	13	14
Riverside	5	72	20	28
Ventura	6	63	12	19

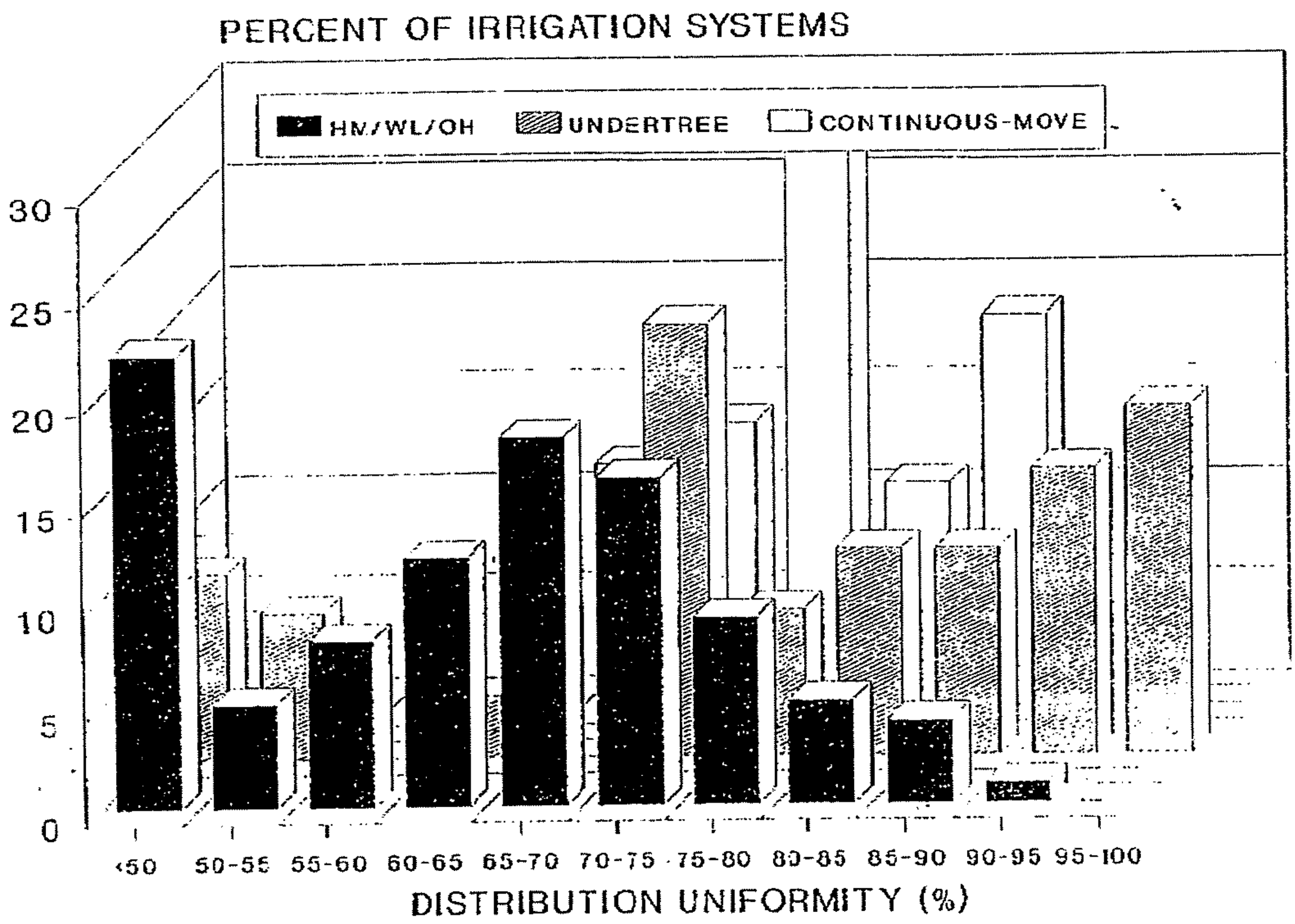
Table 8. Major crop types versus percent of sites and average distribution uniformity.

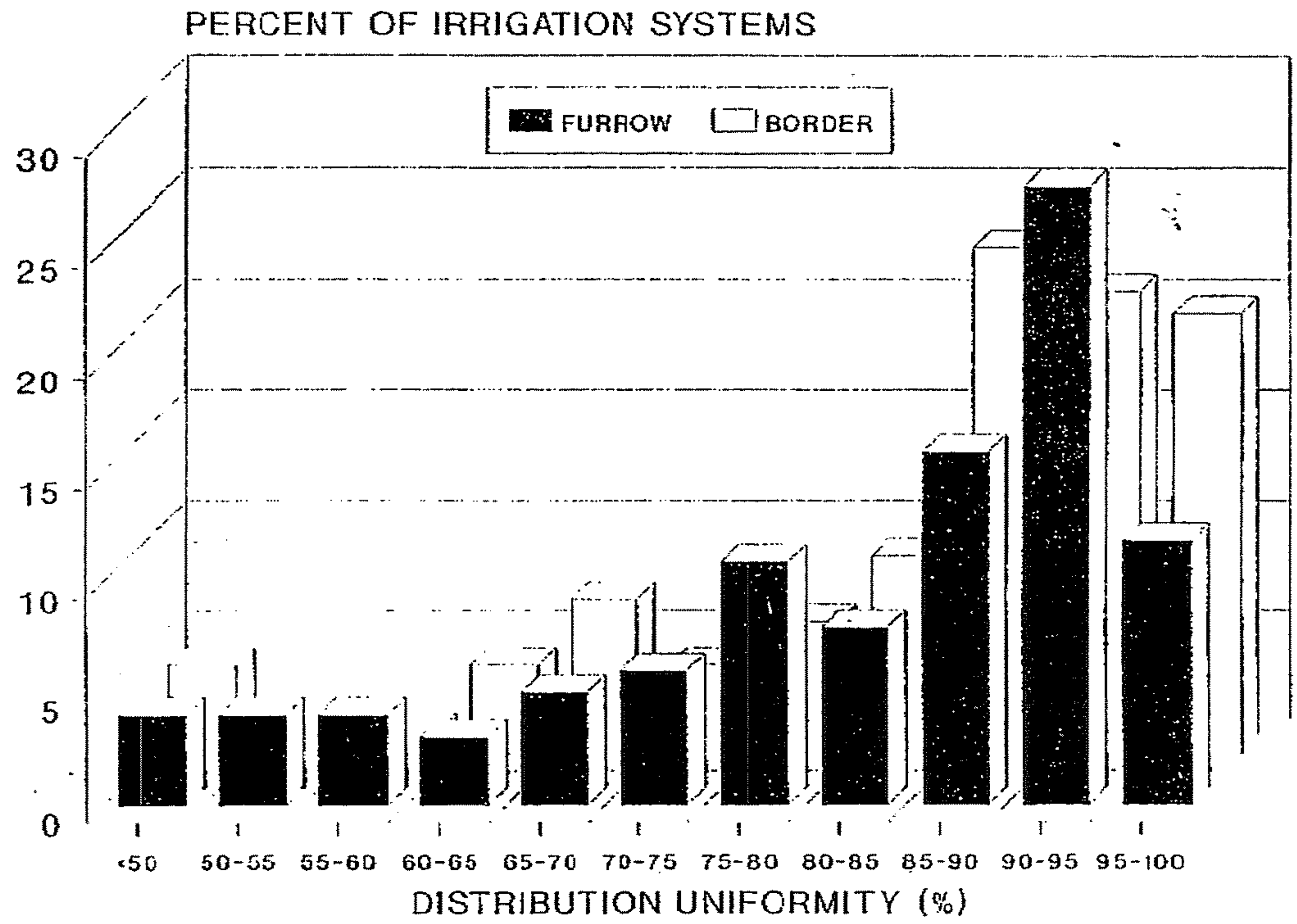
CROP TYPE	PERCENT OF SITES	AVERAGE DISTRIBUTION UNIFORMITY
LOW-VOLUME IRRIGATION		
Citrus	31	80
Avocado	27	68
Grape	13	74
Nut	9	80
Fruit	4	74
CONTINUOUS-MOVE SPRINKLERS		
Alfalfa	53	76
Cotton	19	75
Broccoli	14	74
HAND-MOVE/SOLID-SET SPRINKLER		
Alfalfa	18	59
Cotton	13	64
Lettuce/Cole	11	66
Root	17	64
UNDERTREE SPRINKLERS		
Nut	53	86
Citrus	27	68
FURROW IRRIGATION		
Cotton	50	80
Field Crops	10	86
Tomato	8	90
Citrus	7	59
BORDER IRRIGATION		
Alfalfa	50	83
Nut	35	90



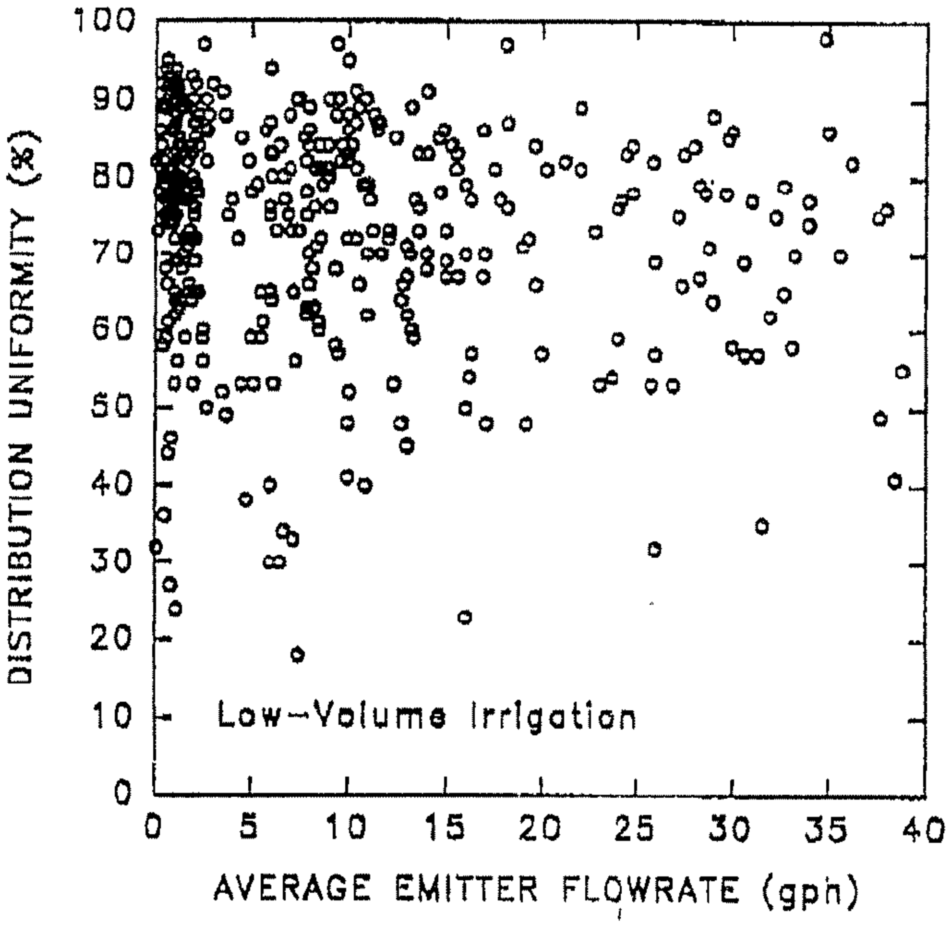
IRRIGATION EFFICIENCY (%)
100
90
80
70
60
50
40
30
20
10
0
Low-Volume Irrigation
0 10 20 30 40 50 60 70 80 90 100
DISTRIBUTION UNIFORMITY (%)


PERCENT OF IRRIGATION SYSTEMS
LOW-VOLUME
20
15
10
5
0
<50
50-55
55-60
60-65
65-70
70-75
75-80
80-85
85-90
90-95
95-100
DISTRIBUTION UNIFORMITY (%)

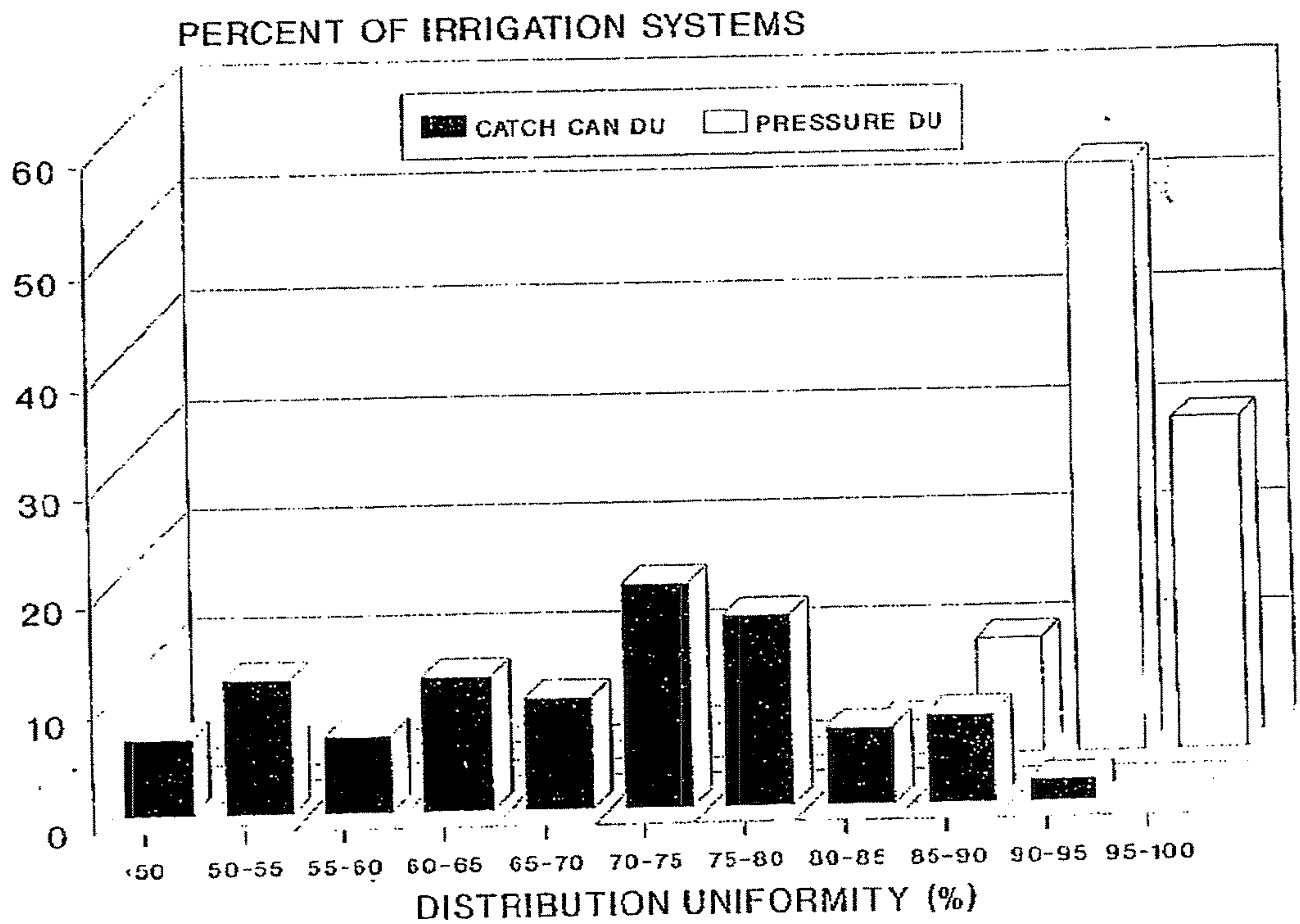

PERCENT OF IRRIGATION SYSTEMS
HM/WL/OH
UNDERTREE
CONTINUOUS-MOVE
30
25
20
15
10
5
0
<50
50-55
55-60
60-65
65-70
70-75
75-80
80-85
85-90
90-95
95-100
DISTRIBUTION UNIFORMITY (%)


PERCENT OF IRRIGATION SYSTEMS
FURROW
BORDER
30
25
20
15
10
5
0
<50
50-55
55-60
60-65
65-70
70-75
75-80
80-85
85-90
90-95
95-100
DISTRIBUTION UNIFORMITY (%)

(4)


100
90
80
70
60
50
40
30
20
10
0
DISTRIBUTION UNIFORMITY (%)
Low-Volume Irrigation
0
5
10
15
20
25
30
35
40
AVERAGE EMITTER FLOWRATE (gph)

5


PERCENT OF IRRIGATION SYSTEMS
CATCH CAN DU
PRESSURE DU
60
50
40
30
20
10
0
<50
50-55
55-60
60-65
65-70
70-75
75-80
80-85
85-90
90-95
95-100
DISTRIBUTION UNIFORMITY (%)

Practical Potential Irrigation Efficiencies

Blaine R. Hanson, M. ASCE[1]

Abstract

Practical potential efficiencies based on achievable high distribution uniformities for micro-irrigation systems and continuous-move sprinkler machines were 80 to 90 percent. Those for periodic-move and portable solid-set sprinkler systems were 70 to 80 percent. Practical potential irrigation efficiencies for furrow and border were 70 to 85 percent.

Introduction

The Environmental Protection Agency (1993) lists expected irrigation efficiencies in California. These expected efficiencies range between 60 percent for conventional furrow irrigation and 95 percent for drip irrigation. These efficiencies, however, are unrealistic. They are too low for furrow irrigation and too high for drip irrigation. They are based on one-year of data from a large scale comparison of various irrigation methods, with one 16.2 ha (40 acre) field per irrigation method (State Water Resources Control Board, 1992). A shallow water table at this site contributed to the low efficiency of the conventional furrow irrigation system.

A practical potential irrigation efficiency is one that is both technically and economically attainable. A realistic estimate of practical irrigation efficiencies is very important because of the potential for regulatory agencies to impose a target irrigation efficiency on agriculture to reduce nonpoint source pollution.

Several estimates of potential irrigation efficiencies can be found (Dickey, 1980; Jensen, 1980; Tanji and Hanson, 1990). Extensive data sets supporting these estimates, however, appear to be lacking. Thus, the objective of this study was to

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[1] Extension Irrigation and Drainage Specialist, Department of Land, Air, and Water Resources, University of California, Davis, CA 95616.

determine practical potential irrigation efficiencies using data from mobile laboratory evaluations of irrigation systems in California.

Procedure

Definitions used for this study are (On-Farm Irrigation Committee, 1978):

1. Irrigation efficiency is the ratio of the average depth of water which is beneficially used to the average depth of irrigation water applied.

2. Distribution uniformity (DU) is the ratio of the average low quarter depth of infiltrated water to the average depth infiltrated.

If the average low quarter depth of infiltrated water equals either the average depth of beneficial use, then the distribution uniformity is an estimate of the potential irrigation efficiency of a properly-managed irrigation system.

Hanson and Bowers (1994) analyzed nearly 1000 data sets of evaluations of irrigation systems conducted by mobile irrigation evaluation laboratories. The system evaluations provided a calculated field-wide or system distribution uniformity, which attempted to account for all major sources contributing to nonuniform application of irrigation water. By analyzing the frequency distribution of the distribution uniformities of each irrigation method, the likelihood of achieving high distribution uniformities could be seen for each method. Thus, the range of achievable high distribution uniformities is a estimate of the range of practical potential irrigation efficiencies.

Results and Discussion

Table 1 shows the sample size and the average distribution uniformity for each irrigation method. The surface irrigation methods had the highest DU's, but these DU's do not reflect field-wide conditions (discussed later). Periodic-move and solid-set sprinklers had the smallest DU's, which reflect wind effects since these DU's are for a single irrigation event. The distribution uniformity of continuous-move systems and microirrigation systems ranged between 71 and 77 percent. The DU of the undertree sprinklers does not reflect any catch-can nonuniformity, which was not included in the evaluation procedure.

The higher average distribution uniformities of the furrow and border systems are misleading. These distribution uniformities are based on infiltration opportunity times along a few furrows of one irrigation set in the field. As such, they do not describe the field-wide or system distribution uniformity, which is affected not only by variability infiltration opportunity times along the furrow length, but also by soil-texture variability, different day and night set times, and time-varying field flow rates during the field irrigation. Average distribution uniformities accounting for these factors would be lower than the values in Table 1. In spite of the weakness of some of the data, these results show that no one irrigation method is distinctively superior to others in terms of field-wide uniformity.

Table 1. Sample size and average field-wide distribution uniformities. Averages with the same letter are statistically similar at a level of confidence of 95 %.

Irrigation Method	Sample Size	Average DU (%)	Standard Deviation (%)
Sprinklers			
Continuous-move	57	75a	10
Portable Solid-set	56	64b	11
Periodic-move	109	61b	17
Under-tree	28	79ade	16
Micro-irrigation			
Microsprinklers	276	71c	14
Drip emitters	163	77ae	14
Surface			
Furrow	157	81d	15
Border	72	84d	14

Table 2 shows the frequency distributions of the DU's for each irrigation method. The likelihood of achieving high DU's can be seen from these frequency distributions. For example, 35 percent of the drip systems had DU's between 81 and 90 percent. This high frequency of occurrence indicates that achieving these DU's is practical. On the other hand, few periodic-move sprinkler systems had DU's greater than 80 percent, indicating that the likelihood is small of achieving DU's greater than 80 percent with this irrigation method. Few of the pressurized systems had DU's greater than 90 percent, suggesting that DU's greater than 90 percent are not practical.

The high frequencies of occurrence of the high DU's of furrow and border irrigation reflect nonuniformity due to only variability in infiltration opportunity times along the furrow. However, soil texture variability throughout a field, not considered in the mobile laboratory evaluations, can have a substantial effect on the uniformity of infiltrated water for surface irrigation methods as found by Childs, et. al, (1993) and Tarboton and Wallender (1989).

Table 2. Frequency distributions (percent of irrigation systems) of the distribution uniformity for each irrigation method.

DU Range	CM	SS	PM	MS	D	F	B
0-10	0	0	1.8	0	0	0	0
11-20	0	0	0.9	0	0	0	0
21-30	0	0	2.8	1.4	1.2	0	0
31-40	1.8	0	7.3	2.5	1.8	2.0	2.9
41-50	1.8	12.5	14.6	4.3	2.4	2.6	1.4
51-60	1.8	21.4	13.8	14.5	6.1	9.2	1.4
61-70	22.8	39.2	29.3	21.3	14.7	5.9	12.9
71-80	38.6	21.4	20.2	27.2	27.0	20.4	10.0
81-90	33.3	5.4	8.2	25	35.0	27.3	35.7
91-100	0	0	0.9	3.6	11.6	32.9	35.7

CM = continuous-move sprinklers, SS = solid-set sprinklers, PM = periodic-move sprinklers, MS = microsprinklers, D = drip emitters, F = furrow, B = border.

Practical potential irrigation efficiencies based on achievable high DU's are in Table 3. The efficiencies of the pressurized irrigation systems are based solely on the frequency distributions in Table 2. Thus, the efficiencies for the surface irrigation systems are adjusted for soil variability, based on the previously-cited research on soil variability and numerous detailed field and computer evaluations of furrow irrigation systems (Hanson, B. R. Unpublished data). These values for surface irrigation also assume that surface runoff is beneficially used.

Table 3. Practical potential irrigation efficiencies.

Irrigation Method	Irrigation Efficiency (%)
Sprinkler	
Continuous-move	80-90
Periodic-move	70-80
Portable Solid-set	70-80
Micro-irrigation	80-90
Furrow	70-85
Border	70-85

Summary

Practical potential irrigation efficiencies based on achievable high distribution uniformities have been determined. These efficiencies are realized by proper design/maintenance of the irrigation systems to achieve the high uniformity of applied water and by managing the system such that the depth of low quarter infiltration equals the depth of benefical use.

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AN ANALYSIS OF MOBILE LABORATORY IRRIGATION SYSTEM EVALUATION DATA: URBAN SYSTEMS

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University of California, Davis

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Chief of Agricultural Water Conservation Section
Division of Local Assistance
California Department of Water Resources, Sacramento

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Associate Land and Water Use Analyst
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California Department of Water Resources, Sacramento

4.34

FAX COVER SHEET

Imperial Irrigation District
Resources Planning and Management Department
333 E. Barioni Boulevard
Imperial, CA 92251
(760)339-9751 phone
(760)339-9009 fax
www.iid.com

Date: 1/8/03

To: Paul Engstrand

From: Tina Shields

No. of Pages Including Cover 9

Transmittal:

Letter to Ruth Thayer, BOR dated September 9, 2002
Estimates of Monthly Diversion Requirements for 2003

Letter to Ruth Thayer, BOR, dated August 15, 2002
Monthly Diversions Estimates for Calendar Year 2003

Letter to Jesse Silva dated July 10, 2002
Estimates of Diversions -- Colorado River 2003

Letter to Jesse Silva dated September 4, 2002
Monthly Diversions Estimates for Calendar Year 2003

Remarks ☐ Urgent ☐ For your review ☒ For your Information ☐ Please comment

TRANSMITTAL COVER SHEET

Imperial Irrigation District
Resources Planning and Management Department
333 E. Barioni Boulevard
Imperial, CA 92251
(760)339-9751 phone
(760)339-9009 fax
www.iid.com

Date: 2/27/03

To: Dr. Dick Tzou 970-224-1885
Associate Engineer
Natural Resources Consulting
Engineers, Inc.

From: Tina A. Shields
Imperial Irrigation District

Attachment: Letter to Ruth Thayer, BOR, dated September 9, 2002
Estimates of Monthly Diversion Requirements for 2003

****

Remarks ☒ Per Request ☐ For your review ☐ For your Information ☐ Please comment

IMPERIAL IRRIGATION DISTRICT

OPERATING HEADQUARTERS • P. O. BOX 937 • IMPERIAL, CALIFORNIA 92251
Tel. (760) 339-9287
Fax. (760)339-9356

WD September 9, 2002

Ms. Ruth Thayer
Attention: BC00-4200
Bureau of Reclamation
P.O. Box 61470
Boulder City, NV 89006-1470

Dear Ms. Thayer:

Subject: Estimates of Monthly Diversion Requirements for 2003
(Your Letter Dated September 4, 2002)

In response to your letter dated September 4, 2002 and pursuant to 43 CFR 417 requirements, enclosed are the estimated 2003 water diversion requirements of Colorado River water at Imperial Dam for use by the Imperial Irrigation District (IID) and the Coachella Valley Water District (CVWD). The estimated water diversion requirement for the IID is based upon the latest predictions of rainfall, as well as, likely 2003 cropping patterns including multiple cropping. Actual diversions in 2003 will, of necessity, reflect changed circumstances as they evolve.

The estimated monthly diversion requirements do not reflect any adjustment for the possible implementation of the Quantification Settlement Agreement (QSA) in 2003. IID remains committed to pursuing the necessary agreements to assure implementation of the QSA by year-end. If and when the QSA is in fact implemented, IID will adjust the 2003 water order as required to meet the obligations under the QSA.

Est 2003

Imperial Irrigation District

9-Sep-02

Estimated 2003 Conserved Water Acre Feet		
Month		Water Conservation Program I.I.D./M.W.D. Conserved Water Diverted at Parker Dam
January		8,667
February		8,667
March		8,667
April		8,667
May		8,667
June		8,667
July		8,667
August		8,667
September		8,667
October		8,667
November		8,667
December		8,663
Total		104,000

Imperial Irrigation District

9-Sep-02

Estimated 2003 Water Diversion Requirements Acre Feet			
Month	IID at Imperial Dam	CVWD at Imperial Dam	Total at Imperial Dam
January	140,000	16,900	156,900
February	170,000	16,800	186,800
March	260,000	26,400	286,400
April	330,000	34,100	364,100
May	350,000	38,300	388,300
June	330,000	36,800	366,800
July	360,000	37,800	397,800
August	310,000	38,700	348,700
September	270,000	32,900	302,900
October	250,000	27,200	277,200
November	180,000	26,000	206,000
December	150,000	18,100	168,100
Total	3,100,000	350,000	3,450,000

United States Department of the Interior

BUREAU OF RECLAMATION
Boulder Canyon Operations Office
P.O. Box 61470
Boulder City, NV 89006-1470

IN REPLY REFER TO:
BCOO-4230
RES-3.10

JUL 1 0 2002

7/30/02

Mr. Jesse P. Silva
General Manager
Imperial Irrigation District
P.O. Box 937
Imperial CA 92251

Subject: Estimates of Diversions - Colorado River 2003 (Due Date August 15, 2002)

Dear Mr. Silva:

Reclamation is directed by Part 417 of Title 43, Code of Federal Regulations (43 CFR 417), to consult with Colorado River water users each year regarding water conservation and the use of Colorado River water. We will be contacting you soon to schedule consultations during September 2002, to discuss your diversion requirements, water conservation activities, and other related topics.

Pursuant to 43 CFR 417 requirements, we are requesting your best estimates of monthly diversion requirements, to be used in conjunction with those furnished by other entities, to plan river operations for the coming calendar year. Please provide this office, Attention: BCOO-4200 with your monthly diversion estimates for calendar year 2003 by August 15, 2002.

If you have any questions, please contact Mr. Steve Jones at 702-293-8186.

Sincerely,

Ruth M. Thayer

Ruth M. Thayer
Group Manager

7/15/02
action: WD

United States Department of the Interior

BUREAU OF RECLAMATION
Lower Colorado Regional Office
P.O. Box 61470
Boulder City, NV 89006-1470

IN REPLY REFER TO:
BCOO-4200
RES-3.10

SEP 04 2002

RECEIVED
SEP - 5 2002
IMPERIAL IRRIGATION DISTRICT
GENERAL MANAGER'S OFFICE

Mr. Jesse Silva
General Manager
Imperial Irrigation District
P.O. Box 937
Imperial, CA 92251-0937

Dear Mr. Silva:

We have begun the process of determining each Contractor's estimated Colorado River diversion requirements for calendar year 2003 under 43 C.F.R. Part 417. To achieve that end, and in light of current water supply conditions, we requested by letter dated July 10, 2002, that you provide your best estimates of your monthly diversion requirements to Reclamation by August 15, 2002.

To date, our request has not been met. Instead, you provided us with various explanations as to why the estimated monthly diversion requirements were not forthcoming, concluding with an expression of hope that these estimates might be available by mid-September.

We are not unsympathetic to the concerns raised in your letter of August 15, 2002; however, the fact remains that Reclamation is charged with making an annual determination of each Contractor's estimated water requirements for 2003. We must therefore move forward expeditiously with the determination of Imperial Irrigation District's (IID) water order and would prefer to do so based on contemporary information provided by you.

Please submit your best estimates of monthly diversion requirements by September 10, 2002, at the latest. This will permit us to take your estimates into account in determining IID's Colorado River water requirements for calendar year 2003. Please note that we have provided you with information about the water order for the Coachella Valley Water District, which you stated is required to assist in the development of IID's diversion estimates.

faxed 9/5 [illegible]
cc Directors
WD
PID
RPM
EO + LE

If you have any questions regarding this second request for 2003 diversion estimates, please contact Jayne Harkins, Area Manager, at (702) 293-8414.

Sincerely,

Robert W. Johnson

Robert W. Johnson
Regional Director

cc Mr. Jerry Zimmerman
Executive Director
Colorado River Board of California
770 Fairmont Avenue, Suite 100
Glendale, CA 91203-1035

4-37

Snyder 12/12/95
WD

Irrigation and Drainage Management and Surface Runoff Reduction in Imperial Valley

Principal Investigators: Khaled M. Bali, Ph.D.
Farm Advisor, Irrigation/Water Management
University of California Cooperative Extension
UC Desert Research and Extension Center
1050 E. Holton Rd., Holtville, CA 95616-9615
(619) 352-9474 Fax: (619) 352-0846 E-mail: kmbali@ucdavis.edu

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Professor, Hydrologic Science, Veihmeyer Hall
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University of California, Davis, CA 95616
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Cooperators: Richard L. Snyder, Ph.D.
Bioclimatologist, Atmospheric Science, Hoagland Hall
University of California, Davis, CA 95616
(916) 752-4628 Fax: (916) 752-1552

Duration of the Project: 3 years (September 1, 1995 - December 31, 1998)

1995

Progress Reports 1 & 2 are contained in Progress report No. 3. Individual reports are coming

Executive Summary:

Colorado River water is the only source of irrigation and drinking water in the Imperial Valley, however it contains more salts than any other surface irrigation source in California. As much as 2.8 million acre-feet of Colorado River water are used every year to irrigate more than 500,000 acres of lands in the Imperial Valley. Surface and subsurface drainage water enters the Salton Sea which serves as a drainage sink for the Imperial and Coachella Valleys since its formation in 1905. The Salton Sea continues to exist because of the drainage water from agriculture in Imperial and Coachella Valleys as well as flow of agricultural drainage and untreated and partially treated sewage from the Mexicali Valley. Because of drainage and its impact on the Sea, several water quality issues exist in the Imperial Valley for which water conservation plays a role.

The Salton Sea water surface elevation has recently (May 1995) reached the highest level in record since 1920. The overall peak elevation for 1994 exceeds that of 1992 by approximately 0.7-0.8 ft. Surface runoff and subsurface drainage water from agricultural lands in Imperial Valley contribute to this increase in elevation. Currently, the salinity of the Sea is nearly 46,000 ppm or approximately 130% the salinity of the Pacific Ocean. Our objective is to conduct a research and demonstration project that will improve irrigation efficiency, reduce surface runoff, utilize the shallow saline water table for new and improved irrigation and drainage management practices, determine crop coefficients for two common field crops (alfalfa and sudangrass) and increase utilization of CIMIS for irrigation scheduling. We are also planing to publish a Handbook about the best management practices for reducing surface and subsurface drainage water. All educational activities will be conducted in cooperation with the Imperial Irrigation District (IID) and the California Department of Water Resources (DWR).

More than 15% of the delivered irrigation water in Imperial Valley becomes tailwater runoff. This water transports significant amounts of chemicals that eventually reach the Salton Sea. Efficient irrigation practices are needed to minimize runoff and to reduce the amount of chemicals in runoff water. This study will focus on development and demonstration of a new method to predict irrigation cutoff time from pre-determined soil moisture status of the clay soil of interest. Issues related to salinity, irrigation management, and water quality will also be addressed in this project. Since soil salinity and water management are affected by water table depth, a major part of this study will be to quantify the effect of water table control on soil salinity, water infiltration rates, and irrigation efficiency. To observe cumulative aspects of reduced water table depth on soil salinity and consumptive water use, this study will be conducted for three years.

Our work will focus on field crops, specifically alfalfa and sudangrass. Field crops account for almost 80% of the 500,000 acres of irrigated land in the Imperial Valley and alfalfa and sudangrass rank 2nd and 7th, respectively, in terms of total production (1993 Imperial County Agricultural Crop and Livestock report). These two major field crops were grown on more than 236,000 acres of irrigated lands in Imperial Valley in 1993.

Educational Elements:

A user-friendly computer program considering practical applications of the BMP's described in Handbook will be developed by the principle investigators. The program will include educational elements about water quality as well as practical applications of surface runoff reduction methods that will be developed as part of this research project at the University of California Desert Research and Extension Center.

Other educational forums of this project include:

1. Irrigation Management and Surface Runoff Conference.
2. Field Days (three).
3. UC Publication Best Management Practices Handbook,
   "BMPs for Irrigation Management and Surface Runoff Reduction in Clay soils".
4. Computer program and worksheets to improve irrigation efficiency in clay soils

A comprehensive guide to irrigation and drainage management and BMPs for runoff reduction in the Imperial Valley will be developed by the principal investigators with contributions from other scientists. This Guide will be completed by December 31 1998 and will be available to growers and the general public. Several field days and seminars will be conducted during the project. Field days, seminars and shortcourses will be conducted by the principal investigators and invited speakers from University of California, Department of Water Resources , Imperial Irrigation District, and farmers. Findings from this research and demonstration project will be published in local, statewide, and national agricultural magazines such as California Agriculture, CA/AZ Farm Press, California Farm Bureau's Ag. Alert, and scientific journals.

Introduction:

Temporal (during the season) variability of infiltration is often the cause of excessive runoff and poor irrigation efficiency in heavy clay soils. The ability to predict changes in infiltration characteristics is the key to improve application efficiency (AE) and distribution uniformity (DU) of surface irrigation systems (Jensen, 1980). Simulation models of surface irrigation systems often use the same infiltration function throughout the season. The ability to predict surface irrigation system performance is directly influenced by temporal and spatial soil variability.

Several investigators have considered different aspects of infiltration variability in irrigated fields. Izadi and Wallender (1985) quantified the effect of soil variability on infiltration characteristics. Linderman and Stegman (1971) showed that infiltration characteristics varied during the season. Vieira et al. (1981) studied the spatial variability of field-measured infiltration rates. Wallender (1986) developed a volume balance furrow irrigation model with spatially varying infiltration characteristics and Bali and Wallender (1987) studied the combined effect of soil variability and intake opportunity time on furrow irrigation systems performance. They also studied field-measured and simulated furrow irrigation system performance under spatially and temporally varied infiltration function parameters. Cracking of soils was most likely the source of variability between simulated and observed field advance rates. Bali et al. (1994)

showed that spatial variability of infiltration in heavy clay soils did not have significant impacts on surface irrigation system performance as compared to temporal variability. Grismer and Tod (1994) tested a field procedure to estimate irrigation time in cracking clay soils using a volume balance method.

Heavy clay soils represents more than 60% of the nearly 200,000 ha of irrigated land in the Imperial Valley, CA. Approximately 16% of the irrigation water is lost to surface runoff due to the limited infiltration in clay soils. Water penetration is usually limited to free water flow into cracks and infiltration parameters vary widely between irrigations over the season. This research will be conducted to study the effect of changes in water table elevation on surface irrigation system performance and surface runoff in a cracking clay soil. The specific objectives of this research and demonstration project are:

1- Determine the best management practices (BMPs) for surface runoff reduction in heavy clay soils of the Imperial Valley.
2- Determine the effect of water table control on irrigation management and consumptive use of water by alfalfa and sudangrass (including crop coefficients for alfalfa and sudangrass).
3- Determine the contribution of shallow saline water tables to crop evapotranspiration in heavy clay soils.
4- Develop a relatively simple approach to predict irrigation cutoff time from pre-determined soil moisture measurements.
5- Develop a user-friendly computer program and irrigation management spreadsheets for efficient irrigation management practices. These tools include: the use of CIMIS for irrigation scheduling, prediction of crop water requirements for alfalfa and sudangrass, and prediction of seasonal changes in AE, DU, and surface runoff.
6- Conduct field days, demonstrations, seminars, and publish results in both popular and scientific media.

This research and demonstration project will be conducted at the University of California Desert Research and Extension Center (UCDREC) near Holtville, CA, a site having soils that are typical of the major acreage of Imperial Valley Soils.

Procedures

A total of 15 acres will be used in this research project. The area will be divided into 2 fields each containing separate plantings of alfalfa and sudangrass. Each field will be further divided into 4 borders where each border is 65 ft*1250 ft.

Field No. 1, Crop: Sudangrass

Sudangrass growing seasons (March-October, 1996, 1997, and 1998)

Planting rates and dates: Sudangrass (cv. 'Piper') will be planted in March 1996, March 1997, and March 1998 at a rate of 120 pounds of seed per acre.

Pest control and harvesting: According to the commercial practices of sudangrass production in Imperial Valley.

Water table control: The water table will be lowered to at least 15 ft below land surface in the upper 500 ft of the middle two borders as compared to a normal water table depth of 4-5 ft below land surface in the proposed field.

Field No. 2, Crop: Alfalfa

Alfalfa growing season (October 1995 - October 1998)

Planting rates and dates: Alfalfa (CUF 101) will be planted in October 1995 at a rate of 30 pounds of seed per acre.
Pest control and harvesting: According to the commercial practices of alfalfa production in Imperial Valley.

Water table control: Tile drains will be blocked in the upper 500 ft of all borders in this field so as to encourage maximum crop use of the shallow water table. Preliminary studies indicate that the water table rises to within 3-4 ft of the land surface in blocked drain fields.

Fields 1 and 2

Colorado River water will be applied to all fields. We will evaluate the irrigation efficiency of each field by taking advance, recession, runoff and flow rate measurements for all borders. Initial infiltration rates will be measured during each irrigation as described by Bali and Wallender (1987) and soil samples will be collected at various depths after each irrigation. The samples will be analyzed for Na, Ca, Mg, K, Cl, and trace elements such as Se and B. Soil moisture distribution in each border will be evaluated using the neutron probe. A total of 32 9-ft neutron probe access tubes will be installed in each field (eight neutron probe access tubes will be installed in each border) to characterize soil moisture distribution in the field. Moisture measurements will be taken at depths of 0.5, 1.0, 1.5, 2.0, 2.5, 3.0, 3.5, 4.0, 4.5, 5.0, 6.0, 7.0, 8.0, and 9.0 ft prior to and two days following each irrigation. Gravimetric soil moisture samples will be taken in the 0-15 cm depth range because the neutron scattering technique does not accurately estimate soil moisture content near the surface. Evapotranspiration estimates during and two days following irrigations will be obtained from a nearby CIMIS weather station (station no. 87) and will be added to the difference in soil moisture prior to and following each irrigation. Soil samples will be regularly taken at various depths to evaluate soil salinity. A total of 32 10-ft observation wells will be installed in each field. Water samples from each well will be taken for chemical analysis of the shallow groundwater throughout the project.

Irrigation scheduling will be based on CIMIS data and on soil moisture measurements as described by Snyder and Bali (1992). Surface runoff and drainage water samples will be taken for chemical analysis. The samples will be analyzed for Na, Mg, Ca, K, Cl, EC, and TDS.

Alfalfa and sudangrass yield will be determined for each cutting and standard statistical analyses will be used to evaluate the effectiveness of different water table elevations. Statistical methods of evaluation will involve the use of ANOVA and time series analysis software.

All irrigations will be started from the south end of the field and advance time will be recorded every 50 ft along each border. The commonly used Kostiakov and modified Kostiakov equations

$$z=kt^a \text{ and} \tag{1}$$

$$z=kt^a+ct, \text{ respectively,} \tag{2}$$

where z is the depth of water infiltrated, t is the intake opportunity time, k and a are empirical constants, and c is the steady infiltration rate, will be used to simulate border irrigation performance in a volume-balance model (Elliott and Walker, 1982). Infiltration function parameters k and a will be obtained for each irrigation and each border from advance data using a power advance function of the form (Walker and Skogerboe, 1987)

$$X=pt^r \tag{3}$$

where X is the advance distance (m), t is the advance time (min), and p and r are fitted parameters. The above power advance function will be used to predict the infiltration function parameters k and a of the Kostiakov equation using the two-point method (Elliott and Walker, 1982). Simulated and field-measured irrigation performance characteristics of border irrigation (AE, DU, surface runoff, deep percolation, and depth infiltrated) will be evaluated for all irrigations using spatially averaged and temporally variable infiltration characteristics.

Advance rates from all irrigations over the season will be correlated with soil moisture content before the corresponding irrigation and actual volume of applied water. An empirical function describing the relationship between moisture content before irrigation and advance rate and cutoff time will be developed for various flow rates and soil moisture depletion levels (see appendix A for details).

The empirical function for eliminating surface runoff will be tested for soil moisture depletion levels between 2.5 and 6 inches over the entire root zone. Statistical methods of evaluation will involve the use of the time series analysis procedures (Davis, 1973).

Summary of work plans:

* sudangrass planted for three successive years on the same ground (Field No. 1)
* Sudangrass planted in March and harvested until October
* alfalfa planted in October 1995 (duration of crop: 3 years, Field No. 2)
* water table lowered from 5 to 15 ft in the upper 500 ft of field No. 1 (sudangrass)
* tile drains blocked in the upper 500 ft of field No. 2 (alfalfa)
* hay yield at each cutting (weighing bales in field)
* infiltration rates and irrigation performance characteristics will be evaluated for each treatment throughout the experiment
* soil samples for chemical analysis will be collected throughout the experiment.
* drainage flow rate will be monitored
* surface runoff will be evaluated and water samples will be collected on a regular basis.

* water table elevation and salinity will be monitored on a regular basis (32 observation wells in each field)
* consumptive water use is determined between irrigations
* ANOVA and time series analysis methods used to determine statistical parameters of concern in the experiments.

Proposed Budget:

	1995-96	1996-97	1997-98	Total
Staff research assistant	$26,700	$27,600	$28,600	
Field Assistants/helpers	$3,600	$3,900	$4,300	
Seed, fertilizer, pesticide, sprinkler, etc. (alfalfa and sudangrass)	$4,500	$2,400	$2,400	
Irrigation and soil sampling supplies	$500	$500	$500	
Pump for drainage water removal and plumbing supplies	$4,000	$400	$400	
Permanent Equipment auger, computer, printer software, and computer supplies for data collections and field days	$3,500	$600	$600	
Field days, short courses expenses and BMP publication cost	$700	$700	$1500	
Reagents and chemical supplies/analysis	$600	$600	$600	
Radiation use authorizations and training on Neutron probe	$350	$400	$400	
Travel To present findings and for travel to/from UCD.	$1,200	$1,200	$1,900	
Subtotal	$45,650	$38,300	$41,200	$124,150
Indirect cost (10%)	$4,565	$3,830	$4,120	$12,415
Total	$50,215	$42,130	$45,320	$137,665

Inkind support:

		1995-96	1996-97	1997-98	1998-99
Total					
University of California					
Personnel and time commitment					
Bali	20%	$10,700	$10,700	$10,700	
Grismer	10%	$8,300	$8,300	$8,300	
SRA (M. Jimenez)	50%	$20,337	$20,337	$20,337	
UCDREC (land & labor)		$11,250	$11,250	$11,250	
Imperial County					
County Funds		$5,592	$5,592	$5,592	
Total inkind support		$56,179	$56,179	$56,179	157,287

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APPENDIX A:

Irrigation scheduling can be based on a relatively simple technique that predicts the cutoff time necessary to minimize runoff and to improve water use efficiency. While the method is applicable for all soils it works best in heavy clay soils. The method is a combination of a volume balance model and a two-point measurement method.

The main objective in heavy clay soils is to have enough water to fill cracks with little or no runoff. The cutoff time can be calculated for a given border using a volume balance model where the total volume of water applied equals the surface storage and the subsurface storage. At any time (t_x) the volume applied, V, is

$$V=Q*t_x$$

Where Q is the inflow rate in cubic feet per second (cfs) and t_x is the time in minutes. The surface storage (SY) equals the product of the average depth of water and the area covered by water

$$SY=\sigma_y*d*w*l_x$$

where σ_y is the surface shape factor (0.6-0.8), d is the depth of water at the water inlet in feet, w is the width of border in feet, and l_x is the advance distance at time t_x.

The subsurface storage (SZ) equals the product of the average depth stored and the area covered by water. Earlier in the irrigation, soil cracks dominate the process of infiltration and the volume of the subsurface storage is essentially the volume of cracks. Thus,

$$SZ=z*w*l_x$$

where z is the average depth stored below the soil surface in feet, and w and l_x are as defined earlier. The total volume, V, is the sum of the surface storage and subsurface storage:

$$V=SY+SZ$$

The average depth stored below the surface can be found at any time, t_x,

$$Q*t_x=(\sigma_y*d*w*l_x)+(z*w*l_x)$$

$$z=\frac{(Q*t_x-\sigma_y*d*w*l_x)}{(w*l_x)}$$

when z is known, the time of cutoff, t_{co}, can be determined to minimize runoff. The total volume applied ($Q*t_{co}$) equals to the volume stored:

$$Q*t_{co}=w*L*z$$

$$t_{co}=\frac{(w*L*z)}{Q}$$

where L is the total length of the border.

The following information is needed to determine cutoff time:

1- Border length and width in feet.
2- Average flow rate in cfs.
3- Depth of the water at the inlet (or soil roughness).
4- One or two points of water advance with time along the border.

Proposed Approach to determine cutoff time:

Our objective is to predict the average depth of infiltration, z, from soil moisture depletion using

$$D=(\theta_{max}-\theta)R$$

where D is soil moisture depletion in feet, $theta_{max}$ is volumetric soil moisture content at saturation, theta is the average volumetric soil moisture content of the root zone before the irrigation event, and R is root zone depth in feet.

Our results have shown that z is directly related to D and R, or in other words z=f(D,R). However, at this time, we will assume that z is a function of D only (z=f(D)). We will evaluate this empirical function from measured values of D and z at several soil moisture depletion levels. Once the function is determined, the cutoff time (t_{co}) can be determined in advance using the following equation

$$t_{co} = \frac{w*L*f(D)}{Q}$$

This equation allows us to predict the time of cutoff before the irrigation event. The advance function can also be predicted. The advance function can be described by

$$x = pt^{r}$$

where t is the time since the start of advance and p and r are fitted parameters ($r \approx 1$ for near linear advance, $r=1$ for linear advance). The average depth stored below the soil surface, z, can be calculated from

$$z = \frac{Q*t_{co}}{W*L}$$

For a linear advance ($x=pt$), the slope of advance, p equals l_x/t_x and when t_x equals t_{co}, l_x is the distance of advance at the time of cutoff, and therefore p can be evaluated from

$$p = \frac{Q}{(\sigma_y*d*W)+(f(D)*W)}$$

Predicted and measured values of p will be compared. The above approach is valid when the soil's bulk density is constant over a wide range of moisture content. However, in clay soils, bulk density is directly affected by moisture content. We will account for this fact by using a bulk density function which is dependent on moisture content.

4-38

Elston Grubaugh.

IMPERIAL IRRIGATION DISTRICT

OPERATING HEADQUARTERS • P O BOX 937 • IMPERIAL, CALIFORNIA 92251

February 28, 2000

Dr. Khaled M. Bali,
Farm Advisor, Irrigation/Water Management
University of California Cooperative Extension
1050 E. Holton Road
Holtville, CA 92250-9615

Re: Draft final report, Contract No. B-80560: Irrigation and Drainage Management and Surface runoff Reduction in the Imperial Valley Project

Dear Dr. Bali,

Thank you for providing us with the opportunity to review and comment on your report. Comments by IID staff are attached.

Sincerely,

John Eckhardt

John Eckhardt, Ph.D., P.E.
Manager, Water Department

cc: Dr. Baryohay Davidoff, DWR
Mr. Wayne Verrill, DWR
Mr. Steve Jones, USBR
✓ Ms. Lauren Grizzle, Imperial Valley Farm Bureau

WR/AJD/Bali_Surface Runoff Reduction_cover.doc

TECHINCAL REVIEW

Irrigation and Drainage Management and Surface Runoff Reduction in the Imperial Valley, DRAFT FINAL REPORT, Bali, et. al., December 1999

Executive Summary

1. The reference in the Executive Summary that, "This report describes the development of a new method to minimize runoff . . ." is hardly accurate. The practice of under-irrigating crops to extend water resources in areas where water is in short supply has been in existence for centuries around the world.

SECTION I *Best Management Practices*

2. Dr. Bali should accurately and completely describe the irrigation system used in his runoff reduction research. Pumping a constant rate from a field reservoir during daylight hours is not typical of surface water irrigation from an open channel canal system in the Imperial Valley. Dr. Bali's research plots experienced none of the head and flow variation inherent in an open channel canal system operated at maximum flexibility. Dr. Bali was able to start his pump when he was ready to irrigate, not necessarily at the Meloland Station's regular turn time. Dr. Bali was able to turn off his pump and end his irrigation events at the precise time he was finished applying water. He did not first have to notify IID for an early shut off and then wait for a zanjero (who is responsible for four canals and over 90 gates) to find the time to accommodate his request. Rather than focusing on a cutback irrigation scheme that, at best, might have limited applicability, perhaps the strongest conclusion that should have been drawn from Dr. Bali's research is the potential benefit of small on-farm and/or mid-lateral reservoirs.

3. Both those who believe that Dr. Bali's work should form the basis of a new irrigation paradigm in the Imperial Valley and those who believe that his work on this project has been flawed should note that a single research project at a state-run experimental station seldom translates into widely adaptable technology. The adoption of technological innovations in agricultural tend to follow a standard model. The wide spread applicability of promising field station research is evaluated across multiple conditions through on-farm demonstration projects. If shown to be applicable across a range of conditions a given technology is adopted over time as it gains acceptance and wider use. Promotion may decrease the time required from introduction to widespread acceptance. Dr. Bali and those who believe that his research should gain immediate acceptance and adoption should refer to <u>*Communication of Innovations*</u> (Rogers and Shoemaker, Collier-MacMillan, 1971) for a better understanding of the process of technology transfer. As I am sure Dr. Bali realizes, promotion of a research innovation before it has demonstrated widespread applicability can kill what may otherwise be a promising ideal. I am sure Dr. Bali also realizes that research with limited applicability will not be adopted regardless of the effort put into its promotion.

4. Having stated the importance of an on-farm demonstration program to the successful dissemination and adoption of agricultural research, Dr. Bali and those who believe that his research should be immediately adopted need to realize that conducting or funding such a program is not the responsibility of the Imperial Irrigation District. Dr. Bali and the UC Cooperative

Extension Service need to identify both cooperating water users and funding. Dr. Bali may wish to consult with his Extension counterparts in Texas concerning their extensive and well-respected on-farm demonstration program which is funded entirely by growers, commodity groups, seed companies, fertilizer and pesticide manufacturers, food processors, irrigation equipment suppliers, and private foundations.

Section II Summary of Field Trials

In general, Section II is greatly lacking in substantive material to support many of the claims promoted in the conclusion. IID has commented previously on many of the reports prepared by Dr. Bali for this project. Likewise, IID and the farm community have continually objected to many of the overly zealous conclusions presented by Dr. Bali. Most pressing are the following:

1. No Scientific Control: The report compares all data gathered in the study to "average values" of sudangrass and alfalfa in the Imperial Valley rather than to a scientific control plot. The lack of a control for comparison purposes is a serious flaw in the study.

2. Soil Type: Section 4.1 Soil Type and Page 33, Paragraph 2: All reference to soil 115 Glenbar silty clay loam should be changed to Imperial-Glenbar silty clay loam. The soil series should be accurately named, although the IID and the NRCS have continually maintained that the soil depicted as an Imperial-Glenbar in the study area is actually closer to a Holtville soil series.

The Imperial-Glenbar soil does not contain a sand lens at the 60-inch depth, as was observed in test pits at the station in the test site area. For Dr. Bali to continually state that the soil in the study area is typical of heavy clay soils in the Valley is misleading and incorrect. The reference used to substantiate this is Zimmerman (1981), see page 32. If one looks in *Section 7 References* in the report, you see this reference is nothing more than an overlay of the SCS Soil Survey for the field station, and the NRCS has maintained that the soil may have been wrongly mapped. Even the soil survey has an accuracy of +/- 10 acres.

Regardless, the soil survey states that Imperial-Glenbar is not well suited to growing alfalfa due to the heaving of the taproot from the soil's shrink-swell action. The fact that the study site seems to grow alfalfa well is another indication that this soil is misdiagnosed in the report.

3. Root Depth: No data is given for sudangrass root development. This needs to be included.

4. Crop Coefficients and Water Table Contribution: Statement on page 46, "The average crop coefficient ((Applied Water, AW + rain + water table contribution, WTC)/ETo) for the entire growing season was 0.84." The reader cannot tell from this formulation whether the crop coefficient or the water table contribution was the independent variable. Indicate how the crop coefficients and how water table contribution were determined.

5. Irrigation Scheduling: Explain how the Water Table Contribution was taken into account in determining when to irrigate and how much to apply, see also Points 6 and 10 below.

6. Water Table Contribution: Add a column indicating Water Table Contribution (WTC) for each irrigation period to Tables 9-11 for Sudangrass irrigation and Table 22 Irrigation information – Alfalfa field. Due to the soil characteristics of the UCDREC study areas, the water table contribution (WTC) is not representative of almost any other Imperial Valley field. Both 18% and 11% are very high.

7. Tailwater Runoff: The average runoff of 2% is not that unusual for sandy fields. This is a clay soil, but lies over a sandy lens below. David Bradshaw of IID's Irrigation Management Unit has pictures provided to him by Dr. Bali that illustrate this. The potential for the water to run to the groundwater may be a major contributor to the low tailwater, and may greatly impact the point in the field at which the irrigation has to be terminated to achieve the results indicated by Dr. Bali.

8. Soil Moisture Depletion: Both study test sites (area 70 and area 80) have soils with similar water holding capacities, see Table 11, page 32. According to Table 11, the available water is 0.2 in/in for depths of 0" to 48" in both areas. As can be seen from Fig. 50, the average root zone for the alfalfa is 30 inches. Thus, by simple math, the available water to the crop is 0.2 in/in times 30 inches = 6 inches total.

The study gives the Kc values for sudangrass as 0.81 and for alfalfa as 0.84. We know that ETo X Kc = ETc. If you multiply the ETo listed in the Table 14 *Irrigation information (sudangrass field) - 1996*, column 3, *ETo since previous irrigation*, by the Kc for sudangrass, you derive the ETc since the last irrigation. ETc is the amount of water the crop would transpire since the last irrigation. Finally, the footnote for Table 11, page 32 states, *Allowable depletion: 50% for most crops, 50-65% for crops that are relatively insensitive to water stress.* Based on these facts and assuming that the sudangrass in the study area had a root depth of 30 inches, we find that the soil stores only 6 inches of water.

Thus, disregarding water table contribution (WTC), plant stress would occur once the crop had extracted 65% of 6 inches or at 3.9 inches, or 65% moisture depletion. From Dr. Bali's data, we can determine that even if the soil were to be at field capacity (6" of available moisture in 30" root zone), the moisture depletion levels exceed the stress soil moisture depletion level at which wilting occurs. This can be seen from the following:

After Table 14, p. 35, **Sudangrass irrigation – 1996 season.** Kc = 0.81, ETc = Kc x ETo, 30" soil profile with 6" Available Water, i.e., Moisture Depletion = ETc/6"

Since Last Irrigation		
ETo (in)	**ETc (in)**	**Moisture Depletion (%)**
Pre-irrigation		
5.04	**4.08**	**68%**
7.57	**6.13**	**102%**
11.51	**9.32**	**155%**
7.87	**6.37**	**106%**
8.43	**6.83**	**114%**
7.40	**5.99**	**100%**

Thus, if the root zone were at field capacity after each irrigation, soil moisture availability prior to the next irrigation on the study sudangrass field would represent moisture depletion levels of 68%, 102%, 155%, 106%, 114%, and 100%. These are all above the allowable 65%.

Alfalfa stress also occurs at 65% depletion, 3.9 inches for a 30" root zone in soil types found in the study area. When values for ETo (in) since previous irrigation are multiplied by the Kc of 0.84, most resultant values are in the wilting point range for alfalfa. Especially look at the dates 9/10/96 and 11/1/96 where ETo is 11.11 inches and 10.75 inches, respectively. That is a moisture depletion of [(0.81 x 11.11)/6] x 100 = 150%.

After Table 22, page 43, **Alfalfa irrigation**, Kc = 0.84, ETc = Kc x ETo, 30" soil profile with 6" Available Water, Moisture Depletion = ETc/6"

Date	Since Last Irrigation		
	ETo (in)	ETc, (in)	Moisture Depletion (%)
12/4/95	2.5	2.10	35%
1/22/96	3.64	3.06	51%
3/19/96	7.65	6.43	107%
4/24/96	9.46	7.95	132%
5/17/96	7.59	6.38	106%
6/7/96	7.16	6.01	100%
7/3/96	8.61	7.23	121%
8/2/96	9.23	7.75	129%
9/10/96	11.11	9.33	156%
11/1/96	10.75	9.03	151%
12/20/96	4.38	3.68	61%
2/19/97	5.9	4.96	83%
4/7/97	9.29	7.80	130%
4/28/97	5.91	4.96	83%
5/19/97	5.88	4.94	82%
6/16/97	8.75	7.35	123%
7/11/97	8.46	7.11	118%
7/23/97	3.2	2.69	45%
8/8/97	4.85	4.07	68%
8/19/97	3.08	2.59	43%
9/5/97	4.13	3.47	58%
10/18/97	8.45	7.10	118%
11/14/97	3.68	3.09	52%
2/13/98	6.89	5.79	96%
3/20/98	4.77	4.01	67%
4/17/98	5.77	4.85	81%
4/29/98	3.20	2.69	45%
5/15/98	4.42	3.71	62%
5/27/98	3.24	2.72	45%
6/12/98	3.63	3.05	51%
6/26/98	5.76	4.84	81%
7/14/98	5.57	4.68	78%

In spite of these results, nowhere in the study is reference made to any plant stress or growth problems, much less a complete plant shutdown that would be expected for these types of soil moisture depletion levels in either sudangrass or alfalfa. In fact, yields are shown to be from 3.78% above the Imperial Valley farmers' average for sudangrass to 1% below the average for alfalfa.

9. Yield Impacts: From yield data provided in the paper, we see that study area yields for sudangrass exceeded average yields produced by Imperial Valley farmers in the first two years of the study; whereas, those for alfalfa exceeded those for the first year. Although, the last two years of alfalfa production were less than the valley average, as Dr. Bali indicates, the reduction in yield was less than 2%.

After Tables 10, p. 32 and 18-20, p. 38. Sudangrass yield (ton/ac), adjusted to 10% moisture

	Imperial Valley farmers		Study Area 70		Study -Valley Farmers	
Year	Area (ac)	**Yield (ton/ac)**	Area (ac)	**Yield (ton/ac)**	Yield (ton/ac)	Study-Farmers/Farmers
1995	77,365	**6.50**			--	--
1996	85,896	**6.36**	7.46	**6.84**	**+0.48**	**+7.02%**
1997	87,562	**5.56**	7.46	**5.90**	**+0.34**	**+5.76%**
1998	70,068	**4.91**	7.46	**4.84**	**-0.07**	**-1.45%**
Ave	80,223	**5.83**	7.46	**5.86**	+0.25	**3.78%**

After Tables 9, p. 32 and 21, p. 39. Alfalfa production (ton/ac), adjusted to 10% moisture

	Imperial Valley farmers		Study Area 70		Study -Valley Farmers	
Year	Area (ac)	**Yield (ton/ac)**	Area (ac)	**Yield (ton/ac)**	Yield (ton/ac)	Study-Farmers/Farmers
1995	182,401	7.88			--	--
1996	161,116	7.56	7.46	**10.51**	**+2.95 ton/ac**	28%
1997	165,922	7.56	7.46	**6.59**	**-0.97 ton/ac**	-15%
1998	178,517	7.65	7.46	**6.62**	**-1.03 ton/ac**	-16%
Ave	171,989	7.66	7.46	7.91	0.32	-1%

10. Water Table Contribution (WTC): With all of this, the conclusion of the study says that makeup water from the aquifer is only 11% to 18% (page 51). As can be seen from the table presented below, while the amount of water available to the crop over the entire season agrees with Dr. Bali's reporting, the water available to the crop root zone is not presented for the reader's consideration. Thus, concerns arise about plant stress and the real water table contribution.

From Dr. Bali's analysis we find that applied water for alfalfa was 149.28 inches, rain was 3.72 inches, and water table contribution was 17.57 inches -- around 11% (Table 22, p. 43 and Table 25, p 49). However, as can be seen from the table below, this calculation was based on the amount needed to meet crop ET (ETc). How it reaches the crop in a way to provide sufficient soil moisture to meet crop requirements is never indicated.

Therefore, as presented in this paper, Dr. Bali has not convinced the reader that the water table contribution was sufficient to meet the crop needs for available water without stress. Furthermore, as far as the reader can tell, ETc and WTC are dependent on each other, and Dr. Bali has not made clear how the value for either of them was obtained as an independent value.

After Table 22, p. 43. Alfalfa Irrigation – Water Table Contribution. Average crop coefficient ((AW+rain+water table contribution, WTC)/ETo) for the entire alfalfa growing season was 0.84.

Julian	Date	Rain since last irr (in)	WTC since last irr (in)		ETc since last irr (in)	Soil Moisture at time of irr	Alfalfa Irr (in)	Soil Moisture after irrigation (in)		Available Soil Moisture @ Stress
			.84 ETo -.75 ETo	Initial SM+ WTC +Rain	.84*ETo			SM @ irr +irr		
	11/8/95						3.91	3.91	3.91	2.1
	12/4/95	0	0.23	4.14	2.10	2.04	3.53	5.57	5.57	2.1
22	1/22/96	0.04	0.33	5.93	3.06	2.88	5.01	7.89	6.00	2.1
78	3/19/96	0.12	0.69	6.81	6.43	0.38	5.52	5.90	5.90	2.1
114	4/24/96	0	0.85	6.75	7.95	-1.19	6.13	4.94	4.94	2.1
137	5/17/96	0	0.68	5.62	6.38	-0.76	5.62	4.87	4.87	2.1
158	6/7/96	0	0.64	5.51	6.01	-0.51	4.99	4.49	4.49	2.1
184	7/3/96	0	0.77	5.26	7.23	-1.97	5.57	3.60	3.60	2.1
214	8/2/96	0	0.83	4.43	7.75	-3.33	5.49	2.17	2.17	2.1
253	9/10/96	0	1.00	3.16	9.33	-6.17	5.28	-0.89	-0.89	2.1
305	11/1/96	0	0.97	0.08	9.03	-8.95	5.30	-3.65	-3.65	2.1
355	12/20/96	0	0.39	-3.26	3.68	-6.94	4.19	-2.75	-2.75	2.1
415	2/19/97	0.32	0.53	-1.89	4.96	-6.85	4.37	-2.48	-2.48	2.1
462	4/7/97	0.12	0.84	-1.52	7.80	-9.33	4.65	-4.68	-4.68	2.1
483	4/28/97	0	0.53	-4.15	4.96	-9.11	4.66	-4.45	-4.45	2.1
504	5/19/97	0	0.53	-3.92	4.94	-8.86	4.57	-4.29	-4.29	2.1
532	6/16/97	0	0.79	-3.50	7.35	-10.85	4.47	-6.38	-6.38	2.1
557	7/11/97	0	0.76	-5.62	7.11	-12.73	5.27	-7.46	-7.46	2.1
569	7/23/97	0	0.29	-7.17	2.69	-9.86	1.42	-8.44	-8.44	2.1
585	8/8/97	0	0.44	-8.00	4.07	-12.08	4.80	-7.28	-7.28	2.1
596	8/19/97	0	0.28	-7.00	2.59	-9.59	1.79	-7.80	-7.80	2.1
613	9/5/97	0	0.37	-7.42	3.47	-10.89	4.59	-6.30	-6.30	2.1
656	10/18/97	1.18	0.76	-4.36	7.10	-11.46	4.60	-6.86	-6.86	2.1
683	11/14/97	0.00	0.33	-6.53	3.09	-9.62	3.40	-6.22	-6.22	2.1
773	2/13/98	1.19	0.62	-4.41	5.79	-10.20	4.58	-5.62	-5.62	2.1
808	3/20/98	0.59	0.43	-4.60	4.01	-8.61	4.60	-4.01	-4.01	2.1
836	4/17/98	0.16	0.52	-3.33	4.85	-8.17	5.15	-3.02	-3.02	2.1
848	4/29/98	0	0.29	-2.73	2.69	-5.42	3.24	-2.18	-2.18	2.1
864	5/15/98	0	0.40	-1.78	3.71	-5.50	4.39	-1.11	-1.11	2.1
876	5/27/98	0	0.29	-0.82	2.72	-3.54	3.87	0.33	0.33	2.1
892	6/12/98	0	0.33	0.66	3.05	-2.39	4.70	2.31	2.31	2.1
906	6/26/98	0	0.52	2.83	4.84	-2.01	4.55	2.54	2.54	2.1
924	7/14/98	0	0.50	3.04	4.68	-1.64	5.07	3.43	3.43	2.1
		3.72	17.72				149.3			
				ETc	165.40	13.8	AF			
				Rain+WTC+Irr	170.72	14.2	AF			
			Runoff (2%)		2.9856					
			Available Water		167.74	14.0	AF			

When Dr. Bali indicates the amount of Water Table Contribution since the previous irrigation event, this particular concern may be alleviated. However, Dr. Bali will have to be sure to indicate very clearly how the determination of the WTC was made.

On the other hand, from the presentation in this paper it is by no means clear that, aside from evaporation, water applied during the preparation irrigation in November was not stored in the soil (raising the water table level) and used by the crop once its root system developed. If this were the case, the water table contribution would be about the same (around 5 inches) in both years. Then the reason for reduced yield in the second year of the study would be under-irrigation. Presenting the water table contribution and yield data more specifically, will address this (unlikely) possibility, as well.

What needs to be done:

1. Indicate how either ETc or WTC was obtained as an independent value.

2. Indicate how the WTC would have been taken up in such a way as not to stress the crop. As can be seen from the table presented in Point 10, the model of WTC = (0.84ETc-0.75 ETo) which must be inferred from the statement on page 44 that indicates: (AW+Rain)/ETo = 0.75 (w/o WTC) 0.84 (including WTC) is not adequate to convince the reader of the author's argument.

3. Present in graphic form the soil moisture water balance, so the reader can see how water is being supplied to the root zone and used by the crop during the irrigation season. Point 2 relates to the crop water requirement of soil moisture of 3.9 inches or more to keep crop stress to a minimum.

4. The Yield and WUE values for the two borders that received the extra irrigation in 1997 as compared with the borders that did not receive extra irrigation (8% increase in AW, 27% to 31% yield increase) need to be provided. Dr. Bali should also indicate impact on the average yield for alfalfa irrigated using his recommended regime for that year.

Other Research, Analysis and Presentation Issues

1. Given the absence of a scientific control, Dr. Bali should make very clear what "average values" were used (yield and water application) to determine the current WUE values against which the study results were compared. Consider the following:

On page 31, Dr. Bali states, "According to UCCE guidelines ... approximately 6.5 ac-ft/ac of water are used annually on alfalfa. ... Approximately ½ ac-ft-ac of water is used for land preparation and approximately another ½ ac-ft/ac is used for leaching." Actually the UCCE Guidelines, recommends a ½ AF flood irrigation for land preparation, and 2 irrigations of ½ AF each for crop establishment (Mayberry, 1996, p 7). In addition, Dr. Bali in his study reports applying about ½ AF flood irrigation for land preparation prior to irrigation for crop establishment. **What irrigations exactly are accounted for in the WUE calculations**; and what was done about these irrigations in this study; i.e., how much water was applied and how was it accounted for?

2. Page 27: The effect of reduced surface runoff irrigations on **alfalfa yield** was only minimal (less than 2% reduction); see also Page 32, Table 9 and Table 10, and Page 51: Effect on alfalfa yield was only minimal (less than 2%) reduction. Please specify whether this is for dry yield or at 10% moisture. Also, give values for expected yield data and source.

Typically, farmers make 8 to 9 cuttings/year. In study, there were 8 cuttings the first year and 7 cuttings the next two years. If an extra irrigation were applied for each of these extra cuttings, the water application would be increased – the impact on the WUE in such a scenario is not known.

3. Runoff reduction implies that runoff was reduced from some percentage to some other percentage. So in the study runoff was reduced **to 2% -- this should be compared to what** value when considering the irrigation recommendations presented in the UCCE Guidelines?

Specific Questions:

1. Page 30: "Except for a few occasions when the IID canal water ran dry during an irrigation event, we had complete control of when to turn the water on or off to (sic) the field." Explained what happened. Why was an irrigation event scheduled during a period when the water supply would be out?

2. Page 37: Cutoff distance guideline – do application flow rate and/or field slope impact the cutoff guideline?

ALFALFA, pages 44 to 49

1. Page 46: Please specify how much of the field is represented by the lower end in, "… almost the entire alfalfa yield at the lower end of the field is commonly lost to scalding."
2. What are typical yields for alfalfa at UCDREC?
3. What happened in 1997 and 1998 to reduce yield to 6 ton/ac from the 10 ton/ac in 1996?
4. Did hay quality vary for these years? Only hay quality information provided is for 1997.
5. Please provide yield and WUE values for the two borders that received the extra irrigation in 1997 as compared with the borders that did not receive extra irrigation (8% increase in AW, 27% to 31% yield increase); also make clear the effect on the overall average
6. Please provide ETc values for alfalfa for the years of the study, and compare water available to the crop with the ETc
7. Explain the source of water from the water table, from what depth does it come, in what amounts, etc.
8. Page 48, to assist the reader, provide a brief description of the mass flow method (Wallender et al. 1979) used to estimate water table contribution – either in the paper or as an appendix
9. Page 49, what was the date of the leaching irrigation and how much water was applied
10. Please provide specific dates for data described in the top paragraph and in Table 25

11. Page 49, notes that "greater upward water movement occurred at the lower end of the field as compared to the upper end of the field." How is it known that the "leaching" was not movement of water to the presumable lower end of the field?
12. Explain what caused the water table contribution to be so greatly reduced after the first year
13. Re Fig. 49, p 71 and comments pages 47 and 48: Explain the mechanism which caused the water table to decrease so much in 1996, less in 1997 and hardly at all in 1998
14. Fig 50, invert scale to match Figs. 46 through 49
15. As an adjunct to Figs 46-49 and in the same layout, provide a Fig. showing the average root depth throughout the growing season
16. Fig. 49: Explain what caused the water table to increase more than 20 inches from Day 600 to Day 650, or so
17. Explain why there was hardly any decrease in the water table from after Day 650, or so, to the end of the experiment
18. Fig 43 & Fig 44. What was done to reduce the Soil Salinity profiles from those shown in Fig. 43 (alfalfa) to those shown in Fig 44 (corn)?
19. In Table 22, page 43, for each irrigation event, provide Julian days as well as Gregorian days.
20. Page 51: Alfalfa crop coefficient 0.84; Sudan grass crop coefficient of 0.81 -- what is typical in the Valley for each?
21. To assist the reader/user, provide a brief description of the Grismer and Tod method (1994) to estimate volume of cracks and cutoff distance or time.

CORN

1. Page 46: What kind of corn was grown? How was it irrigated – using the reduced runoff technique? What was the yield/ac? What was the quality?
2. Please describe the leaching irrigation and amount applied prior to planting sweet corn. How and where do we account for this irrigation in the Water Use Efficiency calculations?

Editorial Comments:

1. Throughout document, style where a numerical range is indicated as "2.8-3.0 million acre-feet" can be confusing, not clear at times if the hyphen is being used as a hyphen or a minus sign. Therefore, where it is meant to indicate 2.8 to 3.0 million acre-feet, use the preposition "to" or in some cases "through" instead of the hyphen/minus sign.
2. Use cut-off or cutoff, choose one style then check throughout for consistency
3. Flow rate is two words in English, Figs. 2-13
4. Paragraph 1: "… an (sic) recently agreed upon allotment of 3.1 MAF of Colorado River water…" The agreement is not finalized, revise this statement
5. Provide Fig. and Table to summarize data included in the Executive Summary
6. Page 2, last paragraph, Line 4: "The effect of reduced surface runoff irrigations…" What is a surface runoff irrigation?

Field 1	Sudangrass		April 1996	April 1997	April 1998	
Field 2	Alfalfa	Nov 95	1996	1997	July 1998	
Fields 1 & 2	Corn					Feb 1999

	Sudangrass (tons/AF/ac)	Alfalfa (tons/AF/ac)
Test AWUE	1.77	1.76
Test WUE	1.75	1.54
CA AWUE		1.80
AZ AWUE		1.49
Imperial Valley AWUE		1.17

7. Please provide the missing data, also tables like the above would assist the reader of the Executive Summary.
8. Page 3, "We found that shutting off…". line 3, reducing runoff to only 1-6% -- begs the question, reducing from what base?
9. Page 3, "Water table contribution (WTC) ,,,", what is the WTC to sudangrass?
10. Page 4, paragraph 1, line 2: change to read: "… improve **on-farm** irrigation efficiency"
11. Page 4, Use of CIMIS reference ET data for irrigation scheduling was not clearly presented in this report
12. Page 6, paragraph 1: … salinity of the Sea is over 47,000 … This statistic is not relevant to the study, unless you mean to show that reducing runoff would increase the salinity of the Sea. If that is your intention, please add the comment
13. Page 6, paragraph 3: "This research and demonstration project was conducted at UCDREC to verify the effectiveness of this method…" To verify what method? The Tod-Grismer procedure, or what? Not clear from this sentence.
14. Page 6. Objective: "The objective of this **Handbook** …" Handbook was not mentioned in the paper title.

15. Page 6: "Irrigation **scheduling** can be based on a relatively simple technique that predicts the cut-off time …" One would use CIMIS to schedule an irrigation, i.e., to determine when to irrigate. It would be better to state, "The cut-off time can be determined using a relatively simple technique."
16. Page 7, first 2 lines: "… the total volume of water applied equals the volume stored on the surface plus that below (subsurface storage)." -- **when there is no runoff**
17. Page 7, paragraph 2: "… volume of applied water can be estimated from **onflow** (sic) rate …" Onflow is not a word in the English language. Replace with "flow rate" wherever it occurs in this report.
18. Page 7, paragraph 2: "Figure 1 schematically illustrates this concept" – the Tod-Grismer concept, or what?
19. Page 7, Fig 1. Provide a title, What is being illustrated in this figure is NOT CLEAR.

20. Page 21: USDA **Soil** (sic) Conservation Service (NRCS). Replace "Soil" with Natural Resources
21. Page 22: Advance ration (ft/min) – is this the advance rate?

22. Page 24: Field Characteristics: Crop & maturity – does this mean Surface roughness? Since a range of values is provided for this parameter, it would be best to use this term
23. Flow rate (cfs) Q – "These measurements are taken when the surface wetting front has advanced ¼ to 1/3 of the border length down the field – how is the user of this material to make this measurement?

24. Page 27: See comments for pages 2 and 3
25. Page 31: focus of this work – Reduce the frequency of application to utilize the shallow ground water (alfalfa fields). This was not evident in the Executive Summary presentation

26. Please provide list of abbreviations